G. W. Olsson Barr

SOLAR HEAT

A SUBSTITUTE FOR FUEL IN TROPICAL COUNTRIES

FOR HEATING STEAM BOILERS, AND OTHER PURPOSES.

BY

WILLIAM ADAMS,

DEPUTY REGISTRAR, HIGH COURT, BOMBAY.

Bombay:
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PREFACE.

THE author first attempted to impart his ideas on the practicability of utilizing solar heat, in a lecture to the members of the Sassoon's Institute, at Bombay; and, subsequently, in the shape of an Essay which he submitted to the Committee of the same Institute, who showed their appreciation of it by awarding to the author the gold medal of the Institute.

He now submits the Essay, considerably amplified, to the public.

SOLAR HEAT.

INTRODUCTION.

THE standard works that have been published upon heat make very little mention of the concentration of solar heat, and are silent on the question of the possibility of using the rays of the sun as a substitute for fuel in tropical countries. A few authors, however, have maintained that the rays of the sun could be utilized and made to perform a number of purposes for which ordinary fuel is used, especially for driving steam machinery. One of these, M. Mouchot, Professor of Mathematics in the Lycée of Tours, in France, has proved the possibility of this by actually setting a steam engine in motion, entirely by concentrated solar rays; and he and Professor Rohlf, the celebrated African traveller, and some French *savans*, are said to be making experiments with the object of using solar heat, concentrated by gigantic revolving burning-glasses, as a motive power for railway locomotives, on a line that they propose to construct across the desert of Sahara. This idea may be, and probably is, purely Utopian, but very important discoveries have been made in striving for the impossible; and if no further success is achieved than that of utilizing the rays of the sun for driving stationary steam engines, an important addition to physical science will have been made, and a great commercial revolution will have been effected. The people inhabiting dry tropical countries will then possess, in their clear skies, a gratuitous and inexhaustible source

of wealth, equal to that which Western nations have to dig, with infinite labour and toil, from the bowels of the earth.

With the exception of Buffon, Mouchot, and Ericsson, none of the few writers who have suggested the use of solar heat as a substitute for fuel, have submitted their theories to the test of experiment. They have treated the question as only a subject of scientific curiosity, and have drawn very erroneous conclusions from unsound premises, which would have been avoided by practical men. The results of actual experiments, however, and the opinions of several eminent men, which are recorded, show such strong grounds for believing that solar heat can be very extensively utilized, that it is a matter of astonishment that, until now, the idea has never been submitted to the test of experiment, on a large scale, in India, where there is by no means a lack of solar heat to concentrate.

With a view of filling up this blank in scientific research, I have recently made a series of experiments in Bombay, the results of which completely convince me that solar heat can be extensively used.

Before describing the experiments which have established that conviction in my mind, I propose to cite the authorities, and refer to the facts that have been ascertained on the subject, by whom and which I was encouraged to make them.

My attention was first directed to the subject in July 1876, by an article in the *Revue des Deux Mondes* of the 1st of May 1876, *L'emploi de la chaleur solaire.* It was a notice of the invention of M. Mouchot's solar heat apparatus, by which the first solar steam engine ever worked in Europe was set in motion, in Paris, in 1866, in the presence of the Emperor Napoleon III. M. Mou-

chot is the author of an able and comprehensive work on solar heat,* to the perusal of which I am indebted for the idea, and for most of the information contained in this book. It is, however, due to myself to observe that, though the idea of making experiments to solve this scientific problem was suggested to me by M. Mouchot, I have not appropriated his invention. This is proved by the fact that I rely principally upon a combination of flat mirrors of silvered glass, which M. Mouchot only speaks of to reject, as of no practical value. At page 68 of his work he says:—

"Comme il n'est pas nécessaire qu'un miroir ardent ait rigoureusement pour foyer soit un point, soit une ligne, on peut encore concentrer assez bien les rayons du soleil au moyen de certaines combinaisons de miroirs plans. Si nous ne donnons pas ici la théorie de cette espèce de reflecteurs, c'est qu'ils offrent peu d'intérêt au point de vue des applications, et que, d'ailleurs, nous aurons bientôt l'occasion d'y revenir en parlant des découvertes des anciens à ce sujet.

"Quelle est maintenant la substance la plus propre à former de bons réflecteurs ? Au premier abord on serait tenté de donner la préférence aux glaces étamées parce qu'elles réfléchissent mieux la lumière que tout autre miroir, et que, de plus, elles sont inalterable à l'air. Mais, d'après ce qu'on sait des propriétés de la chaleur il peut se faire que bon nombre de rayons solaires, après avoir traversé sans difficulté la glace, soient transformés en rayons obscurs par l'amalgame d'étain, et perdent ainsi la faculté de repasser à travers le verre. Or c'est là ce qu'est venue confirmer l'expérience : en outre elle a montré que, jusqu'à présent, le mieux est de s'en tenir aux réflecteurs métalliques."†

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* *La chaleur solaire et ses applications industrielles.* Paris: Gauthier-Villars, 1869.

† "As it is not necessary that an ardent mirror should have rigorously for focus either a point or a line, the rays of the sun

M. Mouchot, in the above quotation, rejects the use of a combination of flat mirrors, and prefers polished metal to silvered glass as a reflecting material. As I hold that a combination of flat mirrors is the only means by which solar heat can be concentrated for practical purposes on a large scale, and that silvered glass is the best, if not the only, reflecting material that can be used, it is obvious that I must be acquitted of the charge of having appropriated his invention. The ancients referred to by M. Mouchot discovered the true solution of this scientific problem, viz. by a combination of flat mirrors.

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can be concentrated very well by means of certain combinations of flat mirrors. If we do not give here the theory of that kind of reflectors, it is because they offer little interest in a practical point of view, and that, besides, we shall soon have occasion to revert to them in speaking of the discoveries of the ancients.

"What is now the best substance for good reflectors? At first sight one would be tempted to give the preference to silvered glass, because it reflects light better than any other mirror. But, after what is known of the properties of heat, it may well be that a great number of solar rays, after having traversed the glass without difficulty, become transformed into obscure rays by the amalgam of tin, and lose thereby the power of repassing through the glass. Experiments have confirmed this, and have moreover shown that, up to the present, it is best to rely on metallic reflectors."*

CHAPTER I.

The historical problem relating to Archimedes —the solution by Anthemius —Descartes — Kircher's experiment—Buffon's compound mirror—an error in the *Encyclopædia Britannica* —Ericsson—Oliver Evans's "singular idea."

Most of the facts relating to the concentration of solar heat were ascertained in consequence of the controversy upon a well-known historical problem.

It is related by some historians that Archimedes succeeded in burning the Roman fleet which, under Marcellus, was blockading Syracuse, by concentrating the rays of the sun upon one of the ships. The truth of that statement was disputed, partly because other historians make no mention of the occurrence, and chiefly because of the supposed impossibility of constructing a concave or parabolic reflector of sufficient dimensions. Anthemius of Tralles, the architect who designed and built the superb basilica of Saint Sophia in Constantinople, proved the possibility of the feat by means of a combination of twenty-four flat mirrors fixed in a frame. His solution of the question is contained in the only fragment that has been preserved of his work on the paradoxes of mechanism. The fragment consists of

four problems relating to ardent mirrors, of which Problems II. and III. bear on the subject. M. Mouchot quotes them at length; they are also quoted in the article on Burning Glasses in the *Encyclopædia Britannica* :—

"Problem II.

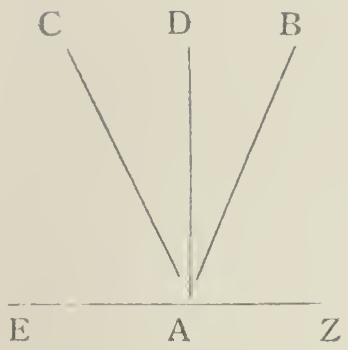
"To construct a machine capable of inflaming, at a given distance, by means of solar rays.

"This problem appears impossible, according to the idea of those who have explained the method of constructing what are called ardent mirrors, for we always see that these mirrors face the sun when inflammation is produced, so that, if the given spot is not in the same alignment as the solar rays, if it incline to one side or the other, or if it is in an opposite direction, it is impossible to execute what is proposed by means of these ardent mirrors. Moreover, the great size of the mirror, which must be in proportion to the distance to which inflammation is required to be effected, compels us to admit that the construction, such as it has been described by the ancients, is nearly impracticable. Thus, according to the descriptions of it that have been given, there is reason to believe that the problem proposed is impossible. Nevertheless, as we cannot deprive Archimedes of the glory that is due to him, since it is unanimously admitted that he burned the enemy's vessels by means of solar rays, reason compels us to acknowledge that by these same means the problem is possible. For us, after having considered it with all the attention of which we are capable, we will expose the method that theory has caused us to discover, first mentioning a few preliminaries necessary to the subject.

"Problem III.

"At a given point of a flat mirror to find a position such that a solar ray striking that point, according to any inclination whatever, may be reflected to another point, also given.

" Let A be the given point, B A the given solar ray from any direction whatever, and that the solar ray, striking the mirror at A, may be reflected on C ; draw a line from A to C, divide into equal parts the angle B A C by the line A D, and imagine the plane mirror E A Z in a position perpendicular to the line A D : it is evident, by what has been demonstrated, that the ray B A striking the mirror E A Z will be reflected at the point C, which should be done.

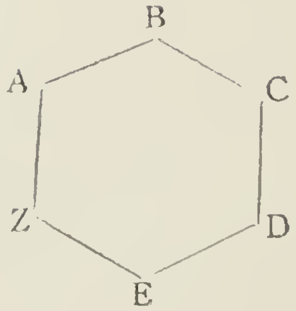


" Consequently also, all the solar rays similarly inclined, and falling parallel to A B upon the mirror, will be reflected by lines parallel to A C. It is therefore demonstrated that wherever the point C may be, in whatever position with regard to the solar ray, that ray will be reflected upon it by the flat mirror. But inflammation takes place by means of ardent mirrors only because many rays are concentrated on the same spot, and that the heat is condensed at the point of intersection to burning power. It is thus that, the fire being kindled in one spot, the surrounding parts of the ambient air conceive some heat in proportion. If then we conceive that, on the contrary, all these degrees of heat be concentrated and united in the middle of this spot, they will there exercise the virtue of fire of which we are speaking. It is necessary, therefore, to reflect upon point C at the distance that we have assigned from point A, and to concentrate upon it other rays by means of similar flat mirrors, in such a manner that all the rays united after the reflection will produce inflammation. And this can be effected by several men holding mirrors which, according to the position indicated, will reflect the solar rays upon the point C.

" But, to avoid the embarrassment that would be occasioned by such an order given to several persons,—for we find that the matter which is proposed to be burned requires not less than twenty-four reflections,—the following is the construction that must be adopted :—

"Solution of Problem II.

"Suppose a flat mirror of an hexagonal shape A B C D E Z, and other adjacent mirrors similar to it attached to the first in straight lines of the smallest possible diameter, so that they are moveable by means of bands which unite and make them adhere together, or by the aid of what are called hinges. If then we arrange the surrounding mirrors upon the same plane as the centre mirror, it is clear



that all the rays will be reflected in a direction conformable to the position of all the parts of the instrument. But if, the centre mirror resting immoveable, we incline upon it with intelligence, as is very easy, all the other surrounding mirrors, it is evident that the rays reflected from them would all tend towards the middle of the point upon which the centre mirror is directed. Let us repeat the operation by surrounding the mirrors of which we have spoken by similar mirrors, all inclining upon the centre; and let us reflect the rays that they receive upon the same point so that all the rays being thus concentrated will produce fire at the given point.

"But this fire will be more easily produced if four or five, or even seven, of such mirrors be employed; and if there is a distance between each analogous to that of the matter to be ignited, so that the rays proceeding from them, mutually intersecting, will render the conflagration more considerable. For if the mirrors are in one place the reflected rays cut each other at very sharp angles, so that the space round the axis becoming heated the inflammation will not take place at the only given point.

"It is therefore possible, by means of ardent mirrors of which we have spoken, and the construction of which we have described, to ignite any inflammable substance at a given distance. Therefore those who have made mention of the mirrors constructed by the divine Archimedes did not mean that he used one mirror only, but several."

Notwithstanding this solution by Anthemius, which was probably forgotten, the controversy was subsequently renewed, and it raged for several centuries. Fortunately there was no religious point involved in the discussion, so no blood was shed. Descartes finally established the opinion that, as the construction of a single mirror having a sufficient range of focus to ignite wood at such a distance as the Roman fleet lay from the walls of Syracuse was impossible, therefore the feat attributed to Archimedes was one of the fictions with which historians embellish history. This opinion prevailed till 1747, when Buffon finally demonstrated the possibility by actually setting fire to a plank of wood at a distance of 150 feet by solar rays reflected from a combination of flat mirrors.

Athanasius Kircher, a celebrated German Jesuit who devoted his intellect to science, and who constructed, amongst other things, a clock which worked by solar heat, on the principle of Solomon de Caux's famous perpetual fountain, took the trouble to make a voyage to Syracuse, for the purpose of studying the problem on the spot. He there comes to the conclusion that a parabolic mirror could be constructed capable of burning inflammable matter at such a short distance as the Roman fleet must have been from the walls of Syracuse, but confesses that he could not succeed in making such a mirror, because the of just form'd mould, heated by the metal in fusion, constantly assumed a spherical form. He then conceives the idea that the purpose could perhaps be effected by a combination of flat mirrors.

He says—

"I took five mirrors. I exposed them to the sun, and found that the light reflected by the first gave me less heat than the direct rays of the sun; with two mirrors there was a notable aug-

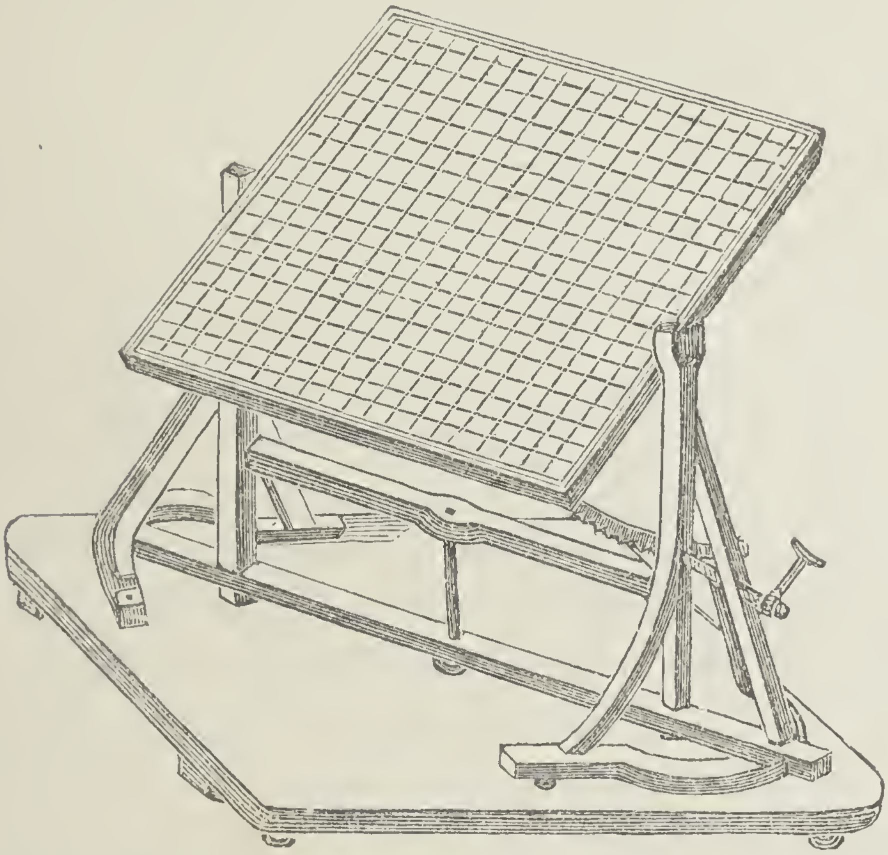
mentation of heat; three gave me the heat of fire; four an intolerable heat; and the heat caused by five mirrors directed on the same point was altogether insupportable. Thence I concluded that, by multiplying the number of mirrors and giving them suitable directions, effects would be produced not only more intense than those obtained at the focus of spherical or parabolic mirrors, but also concentrated to a greater distance. Five mirrors did so at a distance of 100 feet. What terrible phenomena might not be produced if, for example, a thousand mirrors were employed! I earnestly pray mathematicians to try this experiment with great care. It will be found that there is no catoptric apparatus so well calculated to cast ignition to a great distance."

strål brytningen

Buffon, a century afterwards, attempted to carry out Kircher's suggestion.

His experiments, made in the *Jardin du Roi* in Paris, in 1747, are said to have been made with 360 flat glasses fixed in a rectangular frame; but I think there is good reason for believing that this is an error, which has been copied into every account. Both in the *Encyclopædia Britannica* (in the article on Burning Glasses) and in M. Mouchot's work on solar heat, the number of the glasses is given as 360, each eight inches by six inches. If this number be correct, it is singular that no mention is anywhere made of an experiment with the full complement of glasses. In the *Encyclopædia* the largest number said to have been used in any experiment is given as 154, and in M. Mouchot's work as 148. M. Mouchot gives the dimensions of the frame in which these 360 glasses were fixed as eight feet by seven feet, but the *Encyclopædia* omits this detail. Now, a frame eight feet by seven feet would carry exactly 168 glasses, each eight inches by six inches, if placed close together; but the *Encyclopædia* says that there was an interval of "$\frac{1}{3}$ or $\frac{1}{4}$ of an inch," and M. Mouchot says an interval of "four lines," between each glass, which would bring the number

of glasses that the frame would contain down to about 148. For the above reasons I believe Buffon's mirror to have consisted of only 148 flat glasses, and not 360. I take the following account of Buffon's mirror from M. Mouchot's work :—



"The mirror which he caused to be constructed for this purpose was formed of 360 glasses, fixed in a rectangular frame eight feet long by seven feet wide (2 *m.* 60 *de hauteur sur* 2 *m.* 27 *de largeur*). These glasses were each eight inches by six inches. They were moveable in all directions, and there was an interval of four lines between each glass. It took half an hour to arrange them so as to concentrate the solar rays to a focus, but the apparatus, once regulated, could be used as long as the distance of the focus did not require to be changed. This focus was large or small according to its distance from the mirror,—at 50 feet the focus was six inches in diameter; at 150 feet it was sixteen inches. For such distances the curvature of the mirror was so slight that it appeared almost flat. The number of the glasses could be increased or diminished at pleasure. The results of the experiments made with this mirror surpassed the expectation

of Buffon himself. On the 10th of April 1747, after midday, 128 glasses set fire to a plank granträdor of tarred deal at a distance of 150 feet; the ignition was very prompt, and took place over the full extent of the focus, *i.e.*, 16 inches in diameter. On the same day, at 2-30 P.M., a plank of bok beech, tarred in parts and partially covered with lappar shreds of cotton, was ignited. The inflammation took place very suddenly, and the fire became so violent that the plank had to be plunged into water to extinguish it. 148 glasses were used in this experiment, and the distance was 150 feet. On the 11th of April, the focus being 20 feet distant from the mirror, combustible substances were inflamed with 12 glasses. With 21 glasses a plank of beech which had been partially burnt (the plank of the preceding day) was ignited. With 45 glasses a large block of tin weighing 6 lbs. was melted; and with 117 glasses thin sheets of silver were melted, and a plate of sheet iron made red-hot. In further trials, on a fine summer's day, Buffon succeeded in kindling wood at a distance of 68 yards. He also melted most of the metals and metallic minerals at 8, 10, and 13 yards."

Had steam machinery been known in Buffon's time, it is probable that he would have advocated the use of solar heat as a substitute for fuel in tropical countries. He mentions several purposes to which it might be applied, such as calcining gypsum and lime-stone, melting metals, and especially vaporising the water in salt-pans. In what he says on the last-named purpose, however, he shows that he did not understand the true principle of the concentration of solar heat, which is that the solar rays must be collected from a large area to heat a small one.

"For all the evaporations of salt water, in which there is a great consumption of coal or wood, or for which buildings of graduation have to be constructed, at a great cost,—a cost much greater than the purchase of several mirrors such as I suppose,—it would only require twelve mirrors of a foot square each; the heat of these reflected into a focus, although directed below their level, and at a

distance of fifteen or sixteen feet, would be sufficient to make water boil, and consequently to produce a prompt evaporation; for the heat of boiling water is only triple the heat of the sun in summer, and as the reflection of a plain surface, well polished, diminishes the heat only by one-half, six mirrors only would be required to produce, at the focus, a heat equal to that of boiling water. But I double the number of them, so that the heat may be communicated more quickly, and because of the loss occasioned by the obliquity of the rays falling on the water which is required to be evaporated, and also because salt water is heated much more slowly than fresh. This mirror, of which the assemblage would only form a rectangular frame of four feet by three, would be easy to manage and to transport; and if it was proposed to double or triple the effect it would be better to make several similar mirrors—that is to say, to double or triple the number of the mirrors—than to augment the dimensions; for water can only receive a certain degree of heat, and scarcely anything would be gained by augmenting this degree, and consequently the dimensions of the mirror; whereas by having two foci by two mirrors the effect of the evaporation would be doubled; and it would be tripled by three, the foci of which would fall separately upon the surface of the water to be evaporated. Besides, if it is desired to avoid or remedy the loss occasioned by obliquity, it can only be by incurring a still greater loss by first receiving the heat upon a large glass, which will reflect it upon the assemblage of small ones, for then it would burn below instead of burning above; but half the heat would be lost by the first reflection, and half of what remained by the second; so that, instead of six small mirrors, twelve would be required to obtain heat equal to the heat of boiling water. To complete the evaporation more successfully the depth of the water should be diminished as much as possible. A mass of water one foot deep does not evaporate so speedily, by a great deal, as the same quantity reduced to six inches in depth and its superficial area doubled. Besides, the bottom being nearer the surface, it heats more readily, and the heat received by the bottom of the vessel further contributes to the celerity of the evaporation.'"

The above passage shows that Buffon shared the erroneous idea, which, as I shall show, Solomon de Caux and nearly all who have speculated on the effect of concentration have entertained when they have not verified their theories by experiment, that solar rays concentrated to a focus would heat an area larger than the area of reflecting surface. Had Buffon submitted this theory to the test of experiment, he would have discovered that the reflection of the solar rays upon the surface of water would have no effect whatever, partly in consequence of the surface of water reflecting, instead of absorbing, the solar rays, and partly because water can only be heated to ebullition by the heat being applied below it. Even if the water had been confined in a copper vessel, his twelve reflections, from a total area of 4 feet by 3 feet, would not have evaporated a quart of water in a day. He shared the common error that water in contact with a temperature above 212° would boil, whereas it requires a much higher temperature to raise water to 212°. I find that a solid cylinder of water, in a copper vessel holding three gallons, placed in a focus of solar rays having a temperature of 1000 degrees Fahr., takes twenty minutes to be heated to ebullition when the heat is applied to one side of the cylinder. The same focus directed on to the surface of water produces scarcely any effect.

Ericcson, the engineer who invented monitor turret ships, and was the author of several other ingenious inventions,—a Swede who became a naturalized American,—turned his attention to the subject of the concentration of solar heat for driving steam machinery. He died, I believe, without completing his invention, in 1868, soon after writing a letter to his friends in Sweden, of which the following is a fragment:—

"The well-known results of the experiments of Sir John Her-

schel and M. Pouillet, notwithstanding the great interest which they contain, are not sufficiently satisfactory, because they only apply to temperatures of no very great elevation. They only go to show the weight of ice which would be dissolved by the sun in a given time, or the degree of heat which it will impart to water without bringing it to the point of ebullition. The object of my researches and experiments has been to ascertain the precise amount of heat which can be concentrated from the solar rays upon a certain surface, and what are the best means of obtaining such a concentration.

"In the course of this year I have constructed three machines, with the view of obtaining a motive power, and I call them solar machines. One of these machines is set in motion by steam produced by the concentration of calorific rays; the others are moved by the expansive force of the atmospheric air heated directly by the concentrated heat.

"I have not sufficient space to give you a description of these machines, and of the apparatus that I have constructed with the object of concentrating the radiating heat and obtaining the necessary high temperature. I am therefore obliged to limit my description to the principal part of the subject—that is to say, to the motive power itself.

"Consequently, I will tell you that, according to my experiments, when the steam and hot-air machines are at the necessary temperature, the action of the sun upon a surface of ten feet square is capable of vaporising 489 cubic inches of water per hour by means of my apparatus of concentration.

"The importance of this result cannot be over-estimated when we consider that such a vaporisation denotes a flux of heat capable of raising 35,000 lbs. to the height of one foot in one minute, which is more than equivalent to one-horse power.

"This experimental proof of the calorific power of the sun is of greater value than the application of any other physical truth whatever.

"If we reflect that the mean distance of the sun from the earth is 21,444 times greater than the radius of the sun, it will be

found, in squaring that number, that a single square foot of the surface of the sun heats 45,984 square feet of the earth—or, in other terms, that, at an equal surface, the sun emits 45,984 times more heat than the earth receives.

"From this experimental result it may be concluded, with certainty, that a square of 10 feet of the surface of the sun produces heat sufficient to move a steam engine of 45,984 horse power, which is equivalent to the consumption of more than 100,000 lbs. of coal per hour. But in this calculation the real amount of heat emitted by the sun is not placed at its proper value. More than half this heat is lost by the passage of the calorific rays through the atmosphere and by the apparatus of concentration. The solar heat emitted by a surface of 100 square feet corresponds, therefore, to the förbränning combustion of more than 200,000 lbs. of coal per hour. The intensity of the calorific phenomenon signified by such a consumption of coal exceeds the power of the imagination; still less can we conceive the nature and the mass of the matter in ignition, if we reflect that this intense heat is spread over the whole surface of a globe the diameter of which exceeds a hundred times that of the earth. I have no intention of giving you my reflections on the essence of this marvellous planet; the consideration of its wealth as an immense source of motive power, and the use that can be made of it, is the object of this short letter.

"What I have said of my experiments, and the results which they have furnished, prove that, without allowing too great space for the apparatus of concentration, sufficient power can be obtained for practical purposes. The calculations that I have just completed to estimate the mechanical effects of the solar heat falling on the roofs of the houses of Philadelphia show that with this heat more than 5000 steam engines each of 20 horse power could be set in motion. One precious virtue of this new motive power is that it can be gathered without occupying useful space. And, since I have mentioned the question of space, I cannot resist my desire to inform you, by calculation, of the quantity of motive power that can be collected by covering a Swedish mile

of ground with apparatus of concentration and solar machines. Let us admit that half the surface is occupied by buildings, roads, &c. Here then remain $18,000 \times 36,000 = 648,000,000$ square feet of surface upon which the radiating heat can be concentrated. And since my experiments with my apparatus of concentration have demonstrated that 100 square feet are more than sufficient to produce a force equal to one horse, it follows that 64,800 steam engines of 100 horse power each can be set in motion by the radiating heat on a square Swedish mile.. Before terminating this incomplete narration, permit me to ask you: Who can foresee the influence that an inexhaustible motive power is capable of exercising upon civilization, and upon the resources which the earth offers to the human race? You will assuredly learn not without pleasure that other apparatus of concentration, constructed with greater precision, give a greater result than the vaporisation of 489 cubic inches of water per hour and per surface of 100 square feet. I write this letter having before me a solar machine which gives 150 strokes per minute. The object of it is to measure the cubic contents of the steam produced. The experiments of vaporisation are already entirely realised; therefore the apparatus is something more than a mere project. It is now a practical truth which in the future will be held as one of the most indispensable auxiliaries of the human race."

In the above quoted calculation of the amount of solar heat that, in Ericcson's opinion, could be utilised over a Swedish square mile, he leaves out of the account the distance between the mirrors and the objects to be heated, which would diminish his estimate by at least half. I say this on the supposition that he proposed to use, as reflectors, a combination of flat mirrors such as I have adopted and M. Mouchot has rejected. It is evident that he must have had a combination of flat mirrors in his mind, because they are the only kind of reflectors that can be used on the gigantic scale which he suggested.

The last authority that I find in favour of a combination of flat mirrors is in an extract from the *Bulletin de la Société d'Encouragement* for 1821. It is an opinion expressed by Oliver Evans, a distinguished American engineer and mechanician, to the effect that it would not be impossible to heat steam boilers by solar heat reflected from mirrors. The passage occurs in a report on the works of M. de Valcourt, a French engineer who had lived on terms of intimacy with Oliver Evans:—"He (M. Valcourt) reports that the celebrated mechanician said to him one day that it would not be impossible to heat the boilers for steam machinery by means of a large number of mirrors mounted on the same frame and directed on the same point."—And the author remarks—

"Idée singulière qui rappelle en même temps les miroirs d'Archimède et de Buffon, et plusieurs appareils qu'on trouve décrits dans les anciens recueils de machines, et qui avaient pour objet d'élever l'eau par l'intermède de l'air echauffé par les rayons du soleil."

It is evident that, in conceiving this "singular idea" Oliver Evans had also in his mind a combination of flat mirrors precisely such as Ericcson must have used, and as I have experimented with in Bombay, because no other description of reflector can be "mounted on the same frame and directed on the same point."

CHAPTER II.

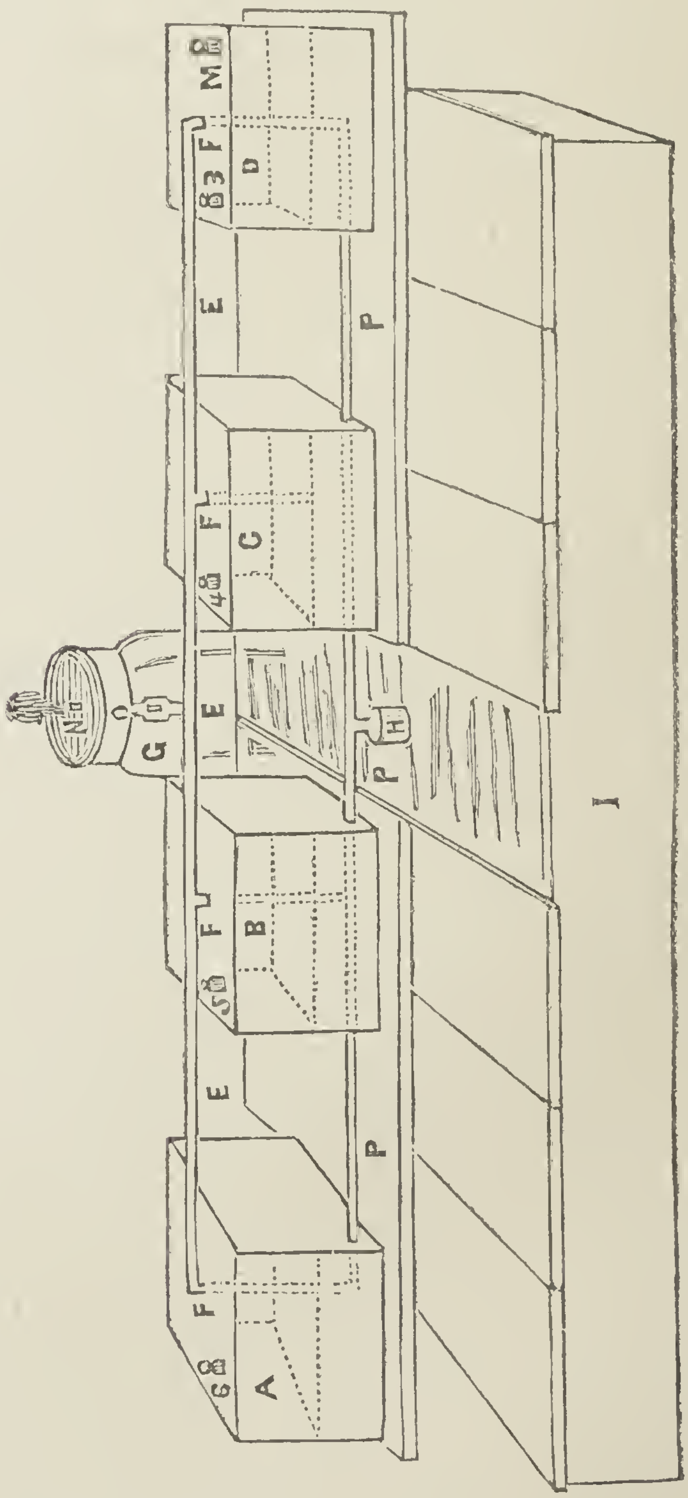
SOLOMON DE CAUX—HIS PERPETUAL FOUNTAIN—THE FIRST TO SUGGEST THE USE OF CONCENTRATION —HIS ERRONEOUS ESTIMATE OF THE POWER OF BI-CONVEX GLASSES—MARTINI'S SOLAR CLOCK—KIRCHER'S SOLAR CLOCK—DE CAUX'S FOUNTAIN IMPROVED BY DE LIANCOURT—ALSO BY MOUCHOT.

The celebrated and unfortunate Solomon de Caux was the first who suggested the application of solar heat to a mechanical purpose, by his famous perpetual fountain. This martyr to science came from Normandy to Paris in the time of Louis XIII., with a petition to the king setting out the wonderful effects that could be produced by steam. According to him, ships and carriages could be propelled, and machinery of all kinds set in motion, by the force of steam from boiling water, and the country that would adopt his invention would be greatly enriched. The idea excited great ridicule in Paris, which only stimulated Solomon de Caux to greater importunity, and he so pestered Cardinal Richelieu that the Cardinal caused him to be confined in the prison of Bicêtre as a lunatic, *pour encourager les autres*, where he languished for several years, till death finally cured him of his insanity.

His perpetual fountain is described in his work *Les Raisons des Forces mouvantes avec diverses machines tants puissantes qu'utiles*, published in 1615. After describing a kind of thermometer by which the intensity of the solar heat can be measured daily, he says—

"I have demonstrated, by the preceding problem, the construction and reason of a continual movement, from which invention

I have taken the present machine, that may be called a perpetual fountain, because the water, which by its nature seeks the lowest level, is raised by solar heat. This machine will have a great effect in warm countries, such as Spain and Italy, because the sun shines there nearly every day, with great heat, especially in summer. The construction will be as follows :—



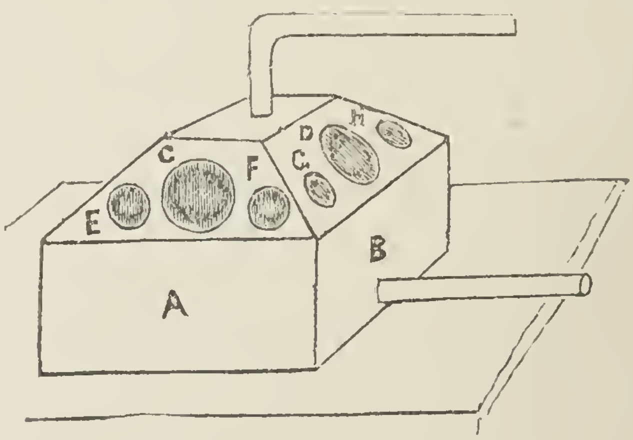
"Have four copper vessels, well soldered all round, each about a foot square, and eight or nine inches high. The vessels will be

marked A B C D. A tube, marked E, is placed upon the said vessels, to which tube will be soldered four branches, each marked by the letter F ; the said branches will be soldered to the top of the vessels, and will descend nearly to the bottom of each vessel. In the centre of the tube there must be soldered a valve, marked G, that will open when the water is propelled upwards through the tube, and reclose when it ceases to rise. There must also be another tube at the bottom of the said vessels, marked P, with four branches soldered to the bottoms of the said vessels, and also a valve, marked H, to the end of which there is a tube descending to the bottom of the water in a cistern or vessel marked I. There must also be upon one of the vessels a hole or vent, marked M. The machine must be placed in a spot where the sun shines upon it, then water must be poured into the vessels through the orifice M, which will enter all the vessels through the tube P, until each vessel is half full of water. Upon another of the vessels there must be another orifice marked O, to allow the escape of air pressed out by the water being poured in. The vessels being thus half filled with water, the vents M and O are hermetically closed. The confined air above the water in each vessel expanding as it becomes heated by the solar rays, the water is forced up through the branches F into the tube E, and thence, forcing open the valve G, into the vessel N. When the air has ceased to expand, and consequently ceased to expel the water, the valve G recloses, and after the heat of the day has passed, and the night shall come, the vessels, to avoid a vacuum, will draw the water from the cistern I through the tube and valve P H, to re-fill the vessels as they were at first, so that this movement will continue as long as there is water in the cistern and the sun shines upon the vessels ; and it must be noted that the valves G and H must be very light, and also well adjusted, so that the water, once raised, cannot descend."

It then occurs to Solomon de Caux that the solar heat falling on the apparatus above described could be greatly increased by the aid of concentration ; but in the means by which he proposes to effect this he shows

that he had the same erroneous idea of the principle of concentration which, as I have shown, was, more than a century afterwards, entertained by Buffon—an idea which, I believe, is very general. If Solomon de Caux had tested by experiment his plans described in the following quotations, and shown in the two accompanying illustrations, he would have found that they would have considerably diminished the heat, instead of increasing it. He says—

"If it is desired to raise the water 5 or 6 feet high, the machine could not do it unless the sun shine with great violence; therefore, to augment the power of the said sun, the copper vessels should be made in the manner shown in the present figure:—

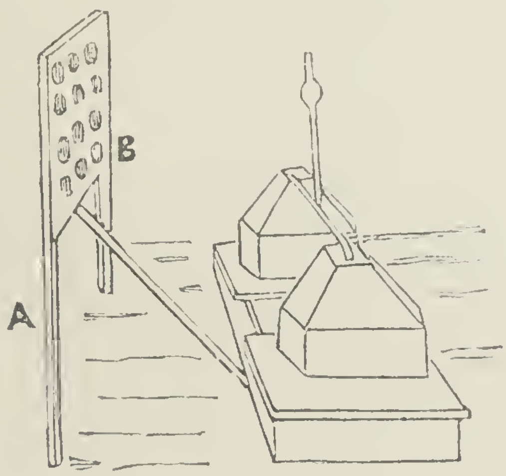


And upon the sides A and B glasses, otherwise called ardent mirrors, should be placed, which should be well adjusted in the copper, so that the air cannot escape. The said glasses shall be marked; the two large ones on each vessel by the letters C and D, and the small ones E F G H; and the side marked B of each vessel must be placed facing the south, so that the sun shining upon it the said ardent glasses may collect the rays of the sun inside the vessels, which will impart a great heat to the water, and the water will by this means issue in greater abundance, and will be raised higher if necessary; and as to the other side of the vessel on which the ardent mirrors are placed, it must be facing the west, to have the solar heat very hot in the afternoon."

He then, to avoid the difficulty of fixing the biconvex glasses firmly in the copper, proposes what he considers

a still better plan than the above, but which, if he had tried it, he would have found that, so far from augmenting the heat, it would have diminished it more than by his first plan. He says—

"In the preceding problem I have demonstrated the means of augmenting the power of the perpetual fountain, but, as it will be difficult to adjust the glasses in the copper so as to prevent the air from escaping through the joints, I will describe another method, which is shown in the present figure :—



The frame A B must be made so as to hold a large number of the said ardent mirrors, which must be placed at a distance of about three feet, so that the points of the ardent cones produced by the said glasses will meet on the vessels. which, being heated by the violent heat of the said glasses, will make the water rise in great quantity. And it will be well to make the said frame large, and to have several glasses fixed in it, in order that, in the sun going its course, there will always be some of them through which the solar rays will be concentrated on the vessels."

Though Solomon de Caux misunderstood the true principle of the concentration of solar heat, the credit is due to him of being the first to suggest the idea of augmenting by it the heat of water in metallic vessels. At the end of his work Solomon de Caux indicates the construction of a solar organ, by which he attempts to explain the tradition relative to the ancient statue of

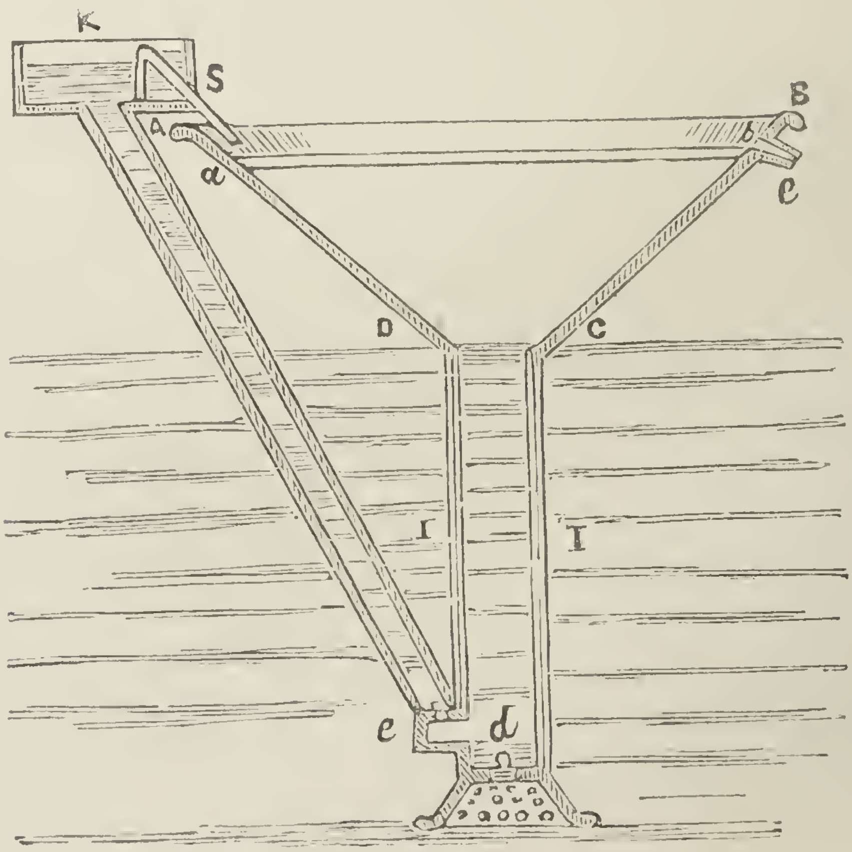
Memnon, which is said to have saluted the rising of the sun by harmonious sounds.

Antonio Martini, Professor of Mathematics in the College of Rome, in 1640 published a work in which he gave the "Explanation of a figure the idea of perpetual motion in the form of a clock," which was to work by the expansion of air heated by solar rays, on the same principle as the perpetual fountain of Solomon de Caux.

Kircher also, in his treatise on the magnet, describes a clock worked by solar heat on the same principle, and he designates Solomon de Caux as the authority on which it is designed.

In 1860 M. De Liancourt invented a solar pump on the principle imagined by Solomon de Caux, with this improvement, that he proposed to empty and refill the machine by alternately placing and withdrawing an object to intercept the solar rays.

Finally, M. Mouchot perfected the invention, as far as it is capable of being perfected, by the apparatus shown in the following drawing:—



"The body of the pump is formed of a funnel or section of a cone reversed, A B C D, terminating in a long cylinder of the same diameter as its lower end C D, which is much narrower than the top of the cone A B. The body of the pump is made of strong cast-iron, with the exception of the upper plate, which is of copper. The platform A B is the surface of the machine to be heated by the solar rays; it is blackened, the better to absorb the heat, and is soldered to the side of the body of the pump a little above the border A B, so as to form a kind of basin in which the water, when raised, may remain for some time before proceeding to its destination through the opening C. The bottom E F of the shaft of the pump is pierced by two openings closed by the valves *d* and *e*. The valve *e* is placed at the entrance of a tube leading to the reservoir K, the bottom of which is a little above the border A B of the body of the pump. Finally, a siphon, S, becomes filled when the water reaches above its curve, and discharges upon the platform *a b*.

"The apparatus being immersed in the water to the level C D, the liquid fills the cylindrical part of the pump. As soon as the sun darts its rays upon the platform *a b*, the latter becomes heated, and, as copper is a good conductor of heat, the heat is quickly communicated to the confined air, which expands, and forces the water through the valve *e* into the reservoir K. If care has been taken to give to this reservoir dimensions so that it will be quite full when the confined air has attained its limit of expansion, the siphon S will empty the reservoir on to the platform. The liquid will then remain on the platform a sufficient time to re-cool it if the orifice C is made much smaller than that of the siphon. The confined air, being thus re-cooled, shrinks to its primitive volume, and the atmospheric pressure forces open the valve *d*, and the water ascends to the level C D. During this time the water on the platform runs off through the tube C, and leaves the platform to be dried and re-heated by the solar rays, when the operation is repeated."

Neither Solomon de Caux, nor any of those who have imagined machines on the principle of his perpetual

fountain, appear to have gone any further than giving descriptions and drawings of their conceptions. I took the trouble of verifying the theory by experiment, and supplemented the direct rays of the sun by concentrating a focus of 360° Fahrenheit upon the confined air by reflection from flat mirrors, but the result was not such as to justify the idea that Solomon de Caux's perpetual fountain, as perfected by M. Mouchot, can be brought into use as a labour-saving invention. My apparatus consisted simply of a copper cylinder provided with two pipes issuing from the bottom, one going upwards like the neck of a swan till it reached above the top of the cylinder, and the other entering another vessel containing water. Both pipes were furnished with taps. The vessel was filled to half its height, and the pipe leading into the vessel below being closed, and that leading upwards being opened, a focus of solar rays of 360° Fahr. was turned on to the upper half of the vessel, when the water was immediately ejected from the pipe leading upwards. When it had ceased to flow, the issue pipe was closed, that entering the water in the vessel below was opened, the focus was turned off, and the cylinder, on cooling, was slowly re-filled by the contraction of the air till it held about the same quantity of water that it had previously contained. The result of this experiment verified the theory, but established the fact that the idea is of no practical value. With a temperature of 360° imparted to the metal within which the air was confined, only one-third of the quantity of water contained in the vessel was ejected. When exposed only to the direct rays of the sun, the water just mounted to the top of the pipe, and a few drops were discharged, but it flowed freely on the vessel being covered with a glass cover.

The expansive force of heated air was used as a motive power, however, long before the time of Solomon de Caux, though he was, perhaps, the first to heat it for the purpose by the concentrated rays of the sun. Heron of Alexandria, a century before the Christian era, described an invention of "the ancients," in the shape of a pious fraud of the Egyptian priests, by which the folding doors of a temple were made to open when the fire for the sacrifice, or burnt offering, was kindled, and to close when it was extinguished, apparently by supernatural agency. The altar was a closed vessel half full of water, in which the air expanded when heated by the fire of the sacrifice, forcing the water through a tube into a bucket. The additional weight communicated to the bucket drew open the doors. When the fire on the altar was extinguished the air shrank to its normal volume, drawing the water back through the tube, out of the bucket, and the bucket, thus lightened, allowed the doors to reclose. By such pious and ingenious artifices the ancient priesthood stimulated the people to feed their brahmans.

CHAPTER III.

Erroneous idea entertained in the eighteenth century—De Saussure's experiment with superposed glasses—Ducarla's conical glasses—Sir John Herschel's experiments—Babinet's burning-glasses.

In the eighteenth century the opinion was entertained, by some scientists, that solar heat could be accumulated to any required intensity under a large number of glasses placed above each other, with an interval between each. This erroneous idea originated by observing that when six or seven glasses were so placed the heat was greatest under the bottom glass; hence it was supposed that the heat continued to augment as the solar rays passed through each successive glass.

The Swiss naturalist De Saussure (1740-1799) says:—

"When I reflected for the first time on these well-known facts, I was much astonished that no physicist had ever ascertained how far this augmentation or concentration of heat could be brought. To make this experiment, then new, I caused to be made, in March 1767, five rectangular cases of Bohemian glass, each of which was the moiety of a cube cut parallel to its base. The first is one foot wide in both ways and six inches high, the second ten inches by five, and so on down to the fifth, which is two inches by one. All these cases are open at the bottom, and are placed, one over the other, upon a very thick table of black pear-tree, to which they are fixed. I used seven thermometers for this experiment, one suspended in the air and entirely isolated by the side of the cases and at the same distance from the surface of the table, another placed upon the exterior case, the next placed upon the second case in the same manner, and so on with

the others, down to the last, which is under the fifth case, and partially embedded in the wood of the table. It must be observed that all these thermometers are of mercury, and that all except the last have the bulb bare, and are not fixed, like ordinary thermometers, in wood or a case, whence the more or less aptitude to absorb or to retain heat causes the results of experiments to vary. This apparatus is exposed to the sun in an open place—for example, on the border wall of a large terrace; I find that the thermometer suspended in the air rises least of all, that on the exterior case a little higher than that on the second case, and so on with the others; but I observe that the thermometer placed on the fifth case rises higher than that partially embedded in the wood of the table. I have seen that on the fifth case rise to 70° R. (214° Fahr.) Fruits exposed to this heat are cooked and yield their juice. When this apparatus is exposed to the sun the whole day the greatest heat is observed towards 2-30 P.M., and when withdrawn from the solar rays it takes several hours to become entirely cool."

He then supposes that he would obtain a still greater heat by hermetically closing the space in which the heat is to be concentrated, and always presenting the opening perpendicularly to the solar rays, for which purpose he makes a deal case, one foot long by nine inches wide, and of a sufficient depth.

"This case, half an inch thick, was lined with black cork an inch thick. I have chosen this bark as being light, and at the same time very close and impenetrable to the heat. Three glasses, fixed in grooves in the thickness of the cork, and placed an inch and a half apart, closed this box so that the rays of the sun could not penetrate to the bottom without passing through them.

"In order that the solar rays should always fall on these glasses perpendicularly, and thus make the greatest impression upon them, and that there should be the least possible reflection, I took care, in my experiments, to turn my case regularly every twenty minutes to follow the apparent movement of the sun, so that its

rays should light the totality of the bottom of the case. The greatest temperature that I could obtain by this means was 228° Fahr., *i.e.* nearly 16° above boiling water.

"But, as I perceived that my box emitted some of the heat as the exterior became sensibly warm, I tried the experiment of placing it in another much larger case stuffed with wadding and only open in the direction of the sun. With this precaution the temperature rose to 230° Fahr., although the weather was not so favourable; so that there is reason to believe that under more favourable circumstances it would have risen to 240 or 250 degrees.

"Finally, to suppress altogether the exterior cooling, I caused a tin pan to be made closed on one side by very clear glass. I placed my instruments in this pan, and exposed it to the sun, taking care, as I have said before, that the rays from the planet entered perpendicularly into the box. Then, according as the heat raised the mercury in the thermometers enclosed in the box, I gradually heated the pan so that the exterior of the box had the same degree of heat as that imparted to the inside by the sun. In spite of these precautions I could never succeed in procuring a degree of heat above 320°. I may be asked, perhaps, why I did not multiply the number of my glasses. I reply, because I was convinced, by a number of comparative experiments, made under circumstances in which I placed all the parity that was in my power, that three glasses accumulated no more heat than two; and in my first apparatus, composed of five cases, I had also perceived very clearly that I obtained no greater heat with five than four, or even with two."

The result of these experiments, it will be seen, was to completely explode the fallacy that intense heat could be concentrated by the multiplication of glasses.

"As to the application," he continues, "I did not flatter myself that I could melt metals; I only thought to make this invention serviceable for purposes which only require heat a little above that of boiling water. I also wished to avoid the adjustment

and loss of time occasioned by the necessity of always presenting the case perpendicularly to the sun. In this view I used hemispheric glass covers fixed one in the other; the largest was twelve inches in diameter, the second ten, and the third eight. Having placed them on a slate table covered with very dry sand to the height of an inch, I found that the thermometer rose only to 189°, as in my cases; by which I saw that I could not even hope to make soup in this apparatus."

The above passages are extracted from two letters of De Saussure, one addressed to Buffon, and the other to the *Journal de Paris*. The object of the second was to combat the opinions of the French philosopher Ducarla, (1738-1816), who maintained that if the temperature under the glass cases did not reach a higher degree, it was because the heat was absorbed by the bodies supporting the apparatus, in proportion as it was concentrated.

Ducarla, in his *Traité du feu complet*, describes an apparatus composed of seven glass covers superposed, with an interval between each, resting on seven other conical glasses, upon which was a hemisphere described as "massive, black, refractory, and dense." This hemisphere is the reservoir in which the heat was to be concentrated, and Ducarla flattered himself that, by exposing this apparatus to the sun and covering it with a thick cloth cover during the night, and in cloudy weather, "*d'entasser et de conserver le feu solaire pour fondre telles et autant de matières qu'on voudrait fût ce après un mois de pluie*,—"to accumulate and preserve the solar fire for melting any substances whatever, even after a month of rain,"—and he recommended the metallurgic industry to construct their furnaces on this model. He does not seem to have verified his theory by experiment, as he says in reply to De Saussure, "I believe I can answer theoreti-

cally for its success. The thing appears worthy of verification." He appears to have had the idea, which had before occurred to Milliet Dechales, of adding a reflector to his glasses, but to have attached very little importance to it, for he says :—"This plan, equally powerful, inconvenient, and costly, will be seldom resorted to. Money will be better employed in the multiplication of glasses."

The reason why the heat was greatest under the bottom glass appears not to have been understood by either De Saussure or Ducarla. It was because solar rays are light only, and not heat, till they encounter an opaque or dark substance, which in De Saussure's experiment was the table, and in Ducarla's the black hemisphere. As, according to Sir John Herschel, thin glass arrests 184 calorific rays out of 1,000, it follows that heat would not penetrate beyond a certain number of glasses, and consequently, as De Saussure perceived, two glasses would accumulate as much heat as five. With five glasses, however, the heat would be retained longer than with two.

Between 1834 and 1838 Sir John Herschel made a series of experiments at the Cape of Good Hope similar to those of De Saussure. They were made under the most favourable circumstances, when the solar rays fell nearly vertical, during the winter solstice. He says :—

"When the heat of the sun is confined and retained, and by that means constrained to accumulate, the temperature increases in a remarkable manner. Thus, a small mahogany box, blackened on the inside, was closed by a pane of glass, but adjusted without mastic, and exposed to the sun so that the rays fell perpendicularly on the glass. A thermometer placed inside the box indicated—

On the 23rd November 1837......65° Centigrade.
" 24th " " ......63°, 66°, 67° Centigrade.

The box was then surrounded with sand, to prevent contact with the air, which raised the temperature to 81° Centigrade. Finally, when this box, with the thermometer which it contained, was placed under a wooden frame, surrounded with sand on every side, and closed also by a sheet of window glass (which made two glass cases), the temperature attained was, on the

3rd December 1867	at 1-30 P.M.	97°	Cent.
,, ,,	1-50 ,,	103°	,,
,, ,,	2-44 ,,	103°	,,

and that whilst a breeze blew on the apparatus. The experiment was repeated in the same manner on the 5th December, with the following result :—

at 12-19 noon	107°	Cent.
12-29 ,,	110°	,,
1-15 P.M.	115°	,,
1-57 ,,	120°	,,
2-57 ,,	116°	,,

"Seeing these temperatures above the point at which water boils, we amused ourselves by making some experiments with eggs, fruit, meat, &c., which we exposed to the solar heat in the same manner, on the 21st December and following days, and the whole was perfectly cooked, after a moderate time of exposure ; the eggs were hard and friable. A stew, consisting of meat and vegetables, was also cooked, on which we all regaled and found the flavour excellent. By augmenting the number of glass covers and making the cases of copper, blackened on the outside, isolating them one from another by supports of wood charcoal, taking care to stuff the exterior case with cotton, and then surrounding the whole with dry sand, I have no doubt that a temperature very near that of ignition would be obtained, and that without resorting to the aid of burning-glasses."

M. Babinet, in describing the experiments of Sir John Herschel, observes that the question of cooking food by solar heat in tropical countries ought to have been decided long ago. He says—

"It is astonishing that, in countries in which the atmosphere

s always clear, as in Egypt, Arabia, and Persia, and where fuel is always scarce and dear, people have never thought of utilizing the concentrated rays of the sun under glass, or by means of burning-glasses and ardent mirrors. With a burning-glass of two or three decimetres in diameter water can be boiled nearly instantaneously. Such a lens can be purchased by weight, and would cost little more than a corresponding weight of ordinary glass, and with it and a few glazed frames it is evident that an oven could be made in the tropics to bake bread, meat, &c."

In the above passage M. Babinet shows that he entertains the same erroneous idea of the principle of the concentration of solar heat as I have shown was entertained by Solomon de Caux and Buffon. It is true that a burning-glass of three decimetres in diameter would boil water, but the quantity would be no greater than would be contained in a vessel of the size of the focus. If applied to a vessel of the same dimensions as the burning-glass, the focus would have no effect whatever. Parker's lens of 2 feet 8 inches in diameter, which cost £700, would perhaps boil water in a vessel holding a pint, but applied to a vessel of its own dimensions it would impart less heat to it than the direct rays of the sun : in other words, by the interposition of a biconvex glass between the direct rays of the sun and an object of its own dimensions, though the heat of the focus would be considerable, the total heat communicated to the bulk of the object would be less than the heat of the direct rays by the quantity absorbed by the glass lens. A biconvex glass can only add to the heat of the direct rays of the sun upon an object smaller than itself. M. Babinet is right, however, in supposing that an oven could be made to bake bread, meat, &c., by solar heat, but the heat must be concentrated by means of reflectors, instead of by biconvex glasses.

CHAPTER IV.

Burning-glasses and concave reflectors—conical reflectors known to the ancients—M. Mouchot's apparatus for heating water, distilling spirits, essences, cooking food, &c.—his solar steam boiler—remarks—improvements suggested—silvered glass compared with metallic reflectors.

The modes of concentrating solar heat most generally known are by means of biconvex glasses, commonly called burning-glasses, and concave metallic mirrors or reflectors. Neither of these are of any use for our purpose. With a biconvex glass the object to be heated, the centre of the glass, and the sun must be in a direct line: therefore it is impossible to use more than one at a time, so as to multiply the heat by uniting a large number of foci into one focus. If this were otherwise, the cost would entirely preclude their use. The famous burning-lens made by Parker, of Fleet Street, was only 2 feet 8 inches in diameter when fixed in its frame, and it cost £700 sterling. Concave reflectors, however, can be used in any number, so as to unite the reflection from each upon any object, but they are nearly as costly as burning-glasses, when the cost of keeping them polished is taken into consideration; and no concave reflector has ever yet been made of more than a few feet in diameter.

The only description of reflector that can be used, as a single reflector, to heat a steam boiler, is a conical or

funnel-shaped reflector, similar to those used for lighting billiard tables. This kind of reflector is very little known as a means of concentrating solar rays. I confess that I never heard of it till about a year ago, when first commencing the study of this interesting subject, but it appears that the concentration of solar heat by conical reflectors was known to remote antiquity. When the sacred fire that burned in the temple of Vesta became extinct, the ancient Romans used to rekindle it by placing a piece of dry wood in the linear focus of a conical reflector. The metal used was brass, and the sides of the reflector had an angle of 45 degrees from the small base. As the worship of Vesta was long anterior, in Italy, to the foundation of Rome, the use of conical reflectors for concentrating solar rays must be of very remote origin. The ancient disciples of Zerdusht, who venerated fire, probably observed the same rite. The fable of Prometheus,—who is said to have stolen the sacred element from heaven,—it is likely, had its origin in the accidental discovery that solar rays are concentrated in a metal dish. Such a discovery, in the credulous ages, would have entitled the discoverer to be supported at the expense of the general community. Now-a-days he would take out a patent. To bring fire from heaven, by supernatural aid and a metallic reflector, was, no doubt, one of the most ancient miracles of priestcraft.

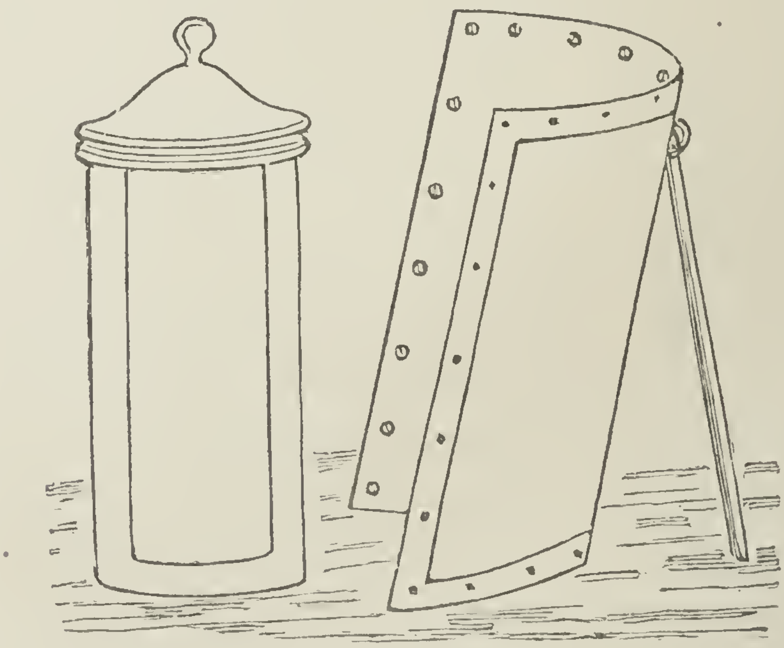
M. Mouchot, who, as I have said, was the first to heat a steam boiler by solar heat, uses a conical reflector of electro-plated copper, precisely similar to that used by the priests of the temple of Vesta, and others, and having the same angle of 45 degrees, which reflects the solar rays upon a steam boiler which is covered with a glass cover. He has been engaged in the study of the utilization of solar heat for more than sixteen years.

He commenced his experiments in 1860, and ensured the priority of his inventions by a patent taken out on the 4th March 1861, No. 48622; but, not wishing to make an object of speculation of it, he abandoned it in 1862. The Emperor Napoleon III. took a lively interest in the experiments made by M. Mouchot. He placed the *atelier impérial des études*, at Meudon, at his disposal, and witnessed, "with astonishment mingled with pleasure," the working of the first steam engine ever driven by solar heat, which was started, at Paris, in the Emperor's presence, in August 1866.

On the 2nd of October 1876, at Paris, M. Mouchot showed me an apparatus which he had that day presented to the *Académie des Sciences*. It consisted of three pieces—a small conical reflector of electro-plated copper, fifty centimetres in diameter, the sides of which were at an angle of 45 degrees; a copper boiler holding a litre of liquid, which was fixed in the centre of the reflector; and a glass cover to envelope the boiler. This apparatus can be used for boiling liquid, distilling spirits or essences, or cooking food, &c. The apparatus is fixed in a socket upon a tripod, and is turned towards the sun on a universal joint, held firm by a screw vice. A French litre of wine in the boiler is boiled in forty minutes, and the alcohol running through a steam pipe is condensed in a helix or worm which passes through a vessel of cold water. The apparatus can also be applied to obtaining the essences that are usually procured by distillation, by filling the boiler with water and placing a vessel containing odoriferous leaves or flowers between the steam pipe and the helix. Food can be cooked by it, by introducing the end of the steam pipe into a cooking vessel. The whole apparatus was neatly packed in a wooden case about two feet square. Provided with this apparatus a traveller

in a tropical country is completely independent of fuel. Since my interview with M. Mouchot at which he showed me the above apparatus, I have ascertained, by often-repeated experiments, that food cooked in an apparatus constructed on the same principle will retain the heat for five or six hours after being withdrawn from the influence of the solar rays. I have often had my solar cooking apparatus withdrawn from the sunshine at 4 P.M., and the food, consisting of meat and vegetables, has been eaten for dinner at 8 P.M. The copper vessel containing the food was invariably too hot to be handled by the naked hand. It was only necessary to cover the glass with a railway rug. The apparatus invented by M. Mouchot will be exhibited at the Paris Exhibition of 1878, as well as his apparatus for generating steam for machinery, which will presently be described.

A more simple way of cooking food practised by M. Mouchot is that shown in the following drawing:—



A copper vessel rests on the bottom of a glass jar, closed respectively by a copper and glass lid, and the rays of the sun are reflected upon it from a cylindrical

metallic reflector. Spirits and essences can be distilled by this contrivance by substituting an alembic for the glass lid, and adding a tube worm or helix. Instead of a cylindrical reflector I use a few flat pieces of silvered glass, which are cheaper and answer the purpose better.

M. Mouchot's apparatus for generating steam for machinery, or solar generator, is on the same principle as that first mentioned. It is composed of three essential parts : a metallic conical mirror or reflector, with a linear focus ; a blackened cylindrical boiler, the axis of which coincides with the linear focus of the reflector; and a transparent glass dome to cover the boiler, which gives free passage to the solar rays reflected from the mirror, and prevents the radiation of obscure heat from the boiler. M. Mouchot asserts that the intensity of heat concentrated by a conical reflector increases in greater ratio than the increase of the dimensions of the reflector,—that is to say, the solar rays concentrated by a conical reflector having two yards of reflecting surface would give more than double the heat of one having one yard of reflecting surface. The rule will probably be found to be the same as the rule with regard to biconvex glasses and concave mirrors, namely, that when the diameter is doubled the total quantity of the heat (*i.e.* the intensity and the area) is quadrupled.

Travellers passing through Tours, on the Orleans railway, may see, in the court-yard of the Public Library, the apparatus in question. It was placed there by permission of the *Conseil général d'Indre et Loire*, and has been frequently exhibited in operation, as an object of scientific curiosity, on summer days when the sky has been clear, during the last five years. The reflector is a section of a cone with parallel bases, of which the sides

form an angle of 45 degrees with the axis. If this section of a cone is divided into equidistant planes parallel to the two bases, the reflector may be considered as formed by a number of annular mirrors, decreasing in circumference and diameter from the large or upper base to the small or lower. If the axis of the cone is directed towards the sun so that the rays fall parallel to a line drawn from the centre of the upper base to the centre of the lower, every ray falling on the interior of the reflector is reflected on that central line. The focus is therefore linear, and the intensity of heat increases in proportion with the increase of the diameter of the circle. This is the best form of reflector for concentrating the solar rays upon a vertical boiler, but it renders a glass dome or cover for the boiler absolutely indispensable, because without it the greatest intensity of heat would be directed upon the upper portion of the boiler, where it has no effect, and very little heat upon the lower portion of the boiler, *i.e.*, the water space, where only heat is effective. In other words, the upper portion of the boiler would receive the heat reflected from an annular mirror of 8 feet 8 inches in diameter (the diameter of the upper base of the reflector), and the lower portion, where heat is effective, would only receive the heat reflected from an annulus of only one metre in diameter (the diameter of the lower base). This is of no consequence when the boiler is covered by a glass dome, because glass, being transparent to solar rays, or light, and not transparent, or non-diathermanous to obscure heat, admits the passage of the solar rays, and, when they become transformed into obscure heat, by contact with the boiler, retains the heat as an envelope of hot air round it. M. Mouchot, in estimating the influence of the glass cover, fails to perceive this, as will be seen from the following passage

from his work. His solar generator is driving a model steam-engine, and he says: *"Pour montrer l'influence du verre en pareil cas, même par un temps calme, il suffissait d'enlever la cloche au milieu de l'expérience; car, le mouvement se ralentissait aussitôt et finissait par s'arrêter, tandis que, pour le voir renaître un instant après, on n'avait qu'à remettre cette cloche en place."** It is, I think, clear, from the above passage, that he ascribes the influence of the glass solely to the facts that it retains the heat round the boiler and prevents radiation, and that he fails to perceive that his angle of 45 degrees has the effect of directing the greatest portion of the heat on to the upper part of the boiler. Further on I shall show how, by a very simple contrivance, the effect of the heat on the boiler would be more than doubled, and how, by varying the angle, every ray can be directed on the water space, which would still further increase the effect; but I doubt whether any disposition of the reflector, or alteration of the boiler, would enable us to dispense with the glass dome.

[illegible] –

The interior surface of the mirror is not of one piece, but is in twelve sections, supported by a framework of iron into which each section is slid in grooves, which allows of each section being taken out and polished to the requisite brilliancy. The diameter of the upper base is 2 m. 60 c. (8 feet 8 inches), and that of the lower, one metre, which gives a normal surface of insolation of four square metres.

* "To show the influence of the glass in such a case, even in calm weather, the cover had only to be removed in the middle of the experiment, for the movement immediately slackened and then stopped, whilst to make it re-commence an instant afterwards the cover had only to be replaced."

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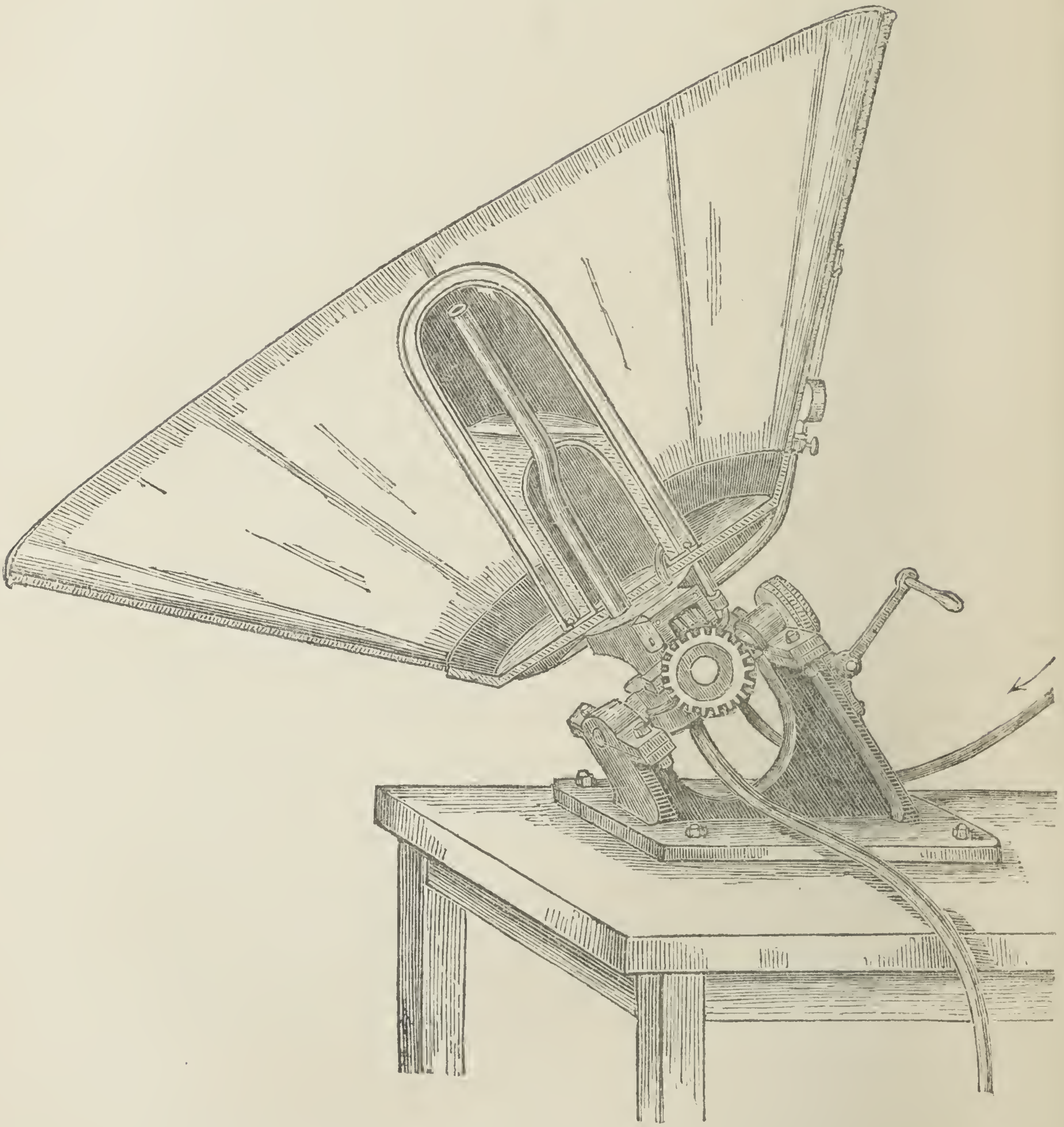
I take the following drawing of the apparatus from a French illustrated paper, *L'Illustration* :—



and the following description from the *Revue des Deux Mondes* of the 1st of May 1876* :—

* *L'emploi de la chaleur solaire.*

"Figure to yourselves a gigantic conical reflector like an immense lamp-shade reversed, turning its concavity towards the sky. The reflector is of copper, plated inside with very thin silver. Upon its small base, closed by a plate of sheet iron, pierced with holes, rests a copper cylinder, blackened on the outside, the axis of which is vertical and the same as that of the reflector. This cylinder, which is thus enveloped as with an enormous collar, is crowned by a hemispheric cap so as to resemble an immense thimble, and is covered by a glass cover of the same shape as the cylinder.

"This apparatus, of an unusual type, is nothing else than a solar receiver, *i.e.* a sort of steam boiler in which water is made to boil under the sole influence of the calorific rays of the sun. This steam generator is intended to bring water into and beyond a state of ebullition, through the effect of the solar rays reflected upon it by the conical reflector. By means of a feed-pipe and a pump, the boiler has water injected into it to above two-thirds of its height. A glass tube and a valve communicating with the interior of the boiler, and which are supported by the exterior of the reflector, indicate the level of the water and the pressure of the steam. Finally, a safety valve is fixed so as to let out the steam if the pressure exceeds the number of atmospheres desired. The engine thus possesses all the security desirable, and can be furnished with every accessory required by a steam boiler. The reflector, or the principal part of the apparatus, is 2 m. 60 c. (8 ft. 8 in.) in diameter at its great base, one metre (3 feet 1 inch) at its small base, and 80 centimetres high (2 feet 7½ inches), which amounts to four square metres (13 feet 2 inches) of reflecting surface or insolation. The inside is of polished silver, but brass slightly electro-plated would do very well. The inclination of the side from the axis is 45 degrees, which is the best angle that can be assigned for metallic mirrors with a linear focus, because the incident rays that fall parallel to the axis are then reflected perpendicularly to the axis, and give a focus of maximum intensity. The boiler is of copper, that metal being the best conductor of heat, and is blackened on the outside, as black has the

property of absorbing the calorific rays, and it is covered with a glass cover, as glass has the property, above all other substances, of being diathermanous to the rays of the sun ; and has, moreover, the property of opposing the passage of these rays when they have been transformed into obscure heat, which happens here by contact on the surface of the boiler.

"The boiler is composed of two concentric bells or vessels, shaped like thimbles, both of copper ; the greatest, which only is visible, is of the same height as the conical reflector, 80 centimetres (2 ft. $7\frac{1}{2}$ in.), and the second, or interior, 50 c. (1 ft. $7\frac{1}{8}$ in.), the two diameters respectively being 28 and 22 centimetres (11 in. and $8\frac{3}{8}$ in.) ; the thickness of the metal is only 3 millimetres ($\frac{1}{8}$ in.). The water is lodged between these two vessels, outside of the smallest and inside of the largest, so as to form an annular cylinder of water 3 centimetres ($1\frac{3}{10}$ in.) wide ; the volume of liquid is thus 20 litres (say $4\frac{1}{2}$ gallons), so as to leave 10 litres for the steam chamber. The inside of the small vessel remains empty, and the steam and feed pipes pass through it. The steam gauge and safety valve branch from the steam pipe. The glass cover or dome by which the boiler is covered is 85 centimetres (2 ft. $9\frac{1}{2}$ in.) high, and 40 (1 ft. 4 in.) in diameter, and is 5 millimetres (13/100 in.) thick—the thickness of an ordinary tumbler. It leaves an interval of 5 centimetres ($1\frac{5}{16}$ in.) between it and the outside of the boiler, thus forming an envelope of hot air, and it is fixed to the bottom of the reflector.

"In consequence of the diurnal and annual revolutions of the earth, the apparatus has to be kept in a position so that its axis shall be perpendicular to the sun at all hours of the day ; therefore it has to be turned an angle of 15 degrees, or $\frac{1}{24}$th of the circumference, per hour, round an axis parallel to the axis of the earth ; that is, to accompany the apparent diurnal movement of the sun, and to incline also gradually upon this axis, having regard to what is called the solar declination. By this means the intensity of the heat utilised is always about the same, whatever the season of the year or hour of the day.

"On the 8th of May 1875, a fine day, 20 litres of water, at 20 degrees, introduced into the boiler at 8-30 A.M., produced steam in forty minutes at two atmospheres (30 lbs.) of pressure to the square inch,) *i.e.* a temperature of 121 degrees, or 21 degrees above boiling water. The steam was then raised rapidly to a pressure of five atmospheres (75 lbs. to the square inch), and if this limit was not exceeded, it was because the sides of the boiler were only three millimetres thick, and the total effort supported by these sides was then 40,000 kilogrammes. It would have been dangerous to have proceeded further, as the whole apparatus might have been blown to pieces.

"Towards the middle of the same day, with 15 litres of water in the boiler, the steam at 100 degrees—that is to say, at a pressure of one atmosphere—rose in less than a quarter of an hour to a pressure of five atmospheres, equal to a temperature of 153 degrees. Finally, on the 22nd of July, towards 1 P.M., an exceptionally hot day, the apparatus vaporised five litres of water per hour, which is equal to a consumption of 140 litres of steam per minute, and to half a horse power. For these experiments the inventor used an engine which made eighty strokes per minute under a continued pressure of one atmosphere. Later on, it was changed for a rotative engine,—that is to say, an engine with a revolving cylinder,—which worked admirably, putting in motion a pump to raise water, until the pump, which was too weak, was broken.

"The double movement required by this apparatus is obtained by means of two gears, which only require each one turn of a crank, the first every half-hour, and the second every eight days. The movement from east to west, which accompanies the apparent course of the sun round the earth, could be made self-acting at a trifling expense."

This combination of a conical reflector, and a cylindrical boiler covered with glass, invented by M. Mouchot, is the most effective plan for concentrating solar heat for heating liquids that can ever be devised. The solar rays rained upon the boiler through the transparent glass

are transformed into obscure heat, and the heat, confined by the glass, accumulates as water accumulates in a lock.

20 litres of water heated to a pressure of 30 lbs. to the square inch in forty minutes, from 8-30 to 9-10 A.M., and then raised to a pressure of 75 lbs. by concentration of the solar rays from a reflecting surface of four square metres, is, it must be admitted, a great triumph of ingenuity, the more creditable to M. Mouchot as he conceived the idea, and proved his theory by the test of experiment, without any suggestion from any of his predecessors in the study of this important problem. With the exception of the two alterations which I am about to propose, I believe that M. Mouchot's invention is incapable of further improvement. The first is to perforate the annulus of water in the boiler with two or more tubes, by which means the heat inside the inner dome would be of the same temperature as that between the glass and the exterior of the boiler, and the effect would consequently be more than doubled. The second is to give to the reflector M. Mouchot's angle of 45 degrees, only up to the surface of the water space, and thence upwards at such greater angle as would reflect all the solar rays upon the water space. With the glass cover this second alteration would, perhaps, be no great improvement, but without it water can only be brought to ebullition, in a funnel-shaped reflector, by having the rays reflected upon the water space.

There are, unfortunately, however, several reasons why this ingenious invention will never be brought into practical use, which will readily occur to the reader. A reflector of polished metal, similar to that of M. Mouchot's, is too expensive. It would be impossible to construct one of much greater dimensions than his, which was 8 feet 8 inches in diameter, and only heated a boiler of half a

horse power, and the difficulty, and consequent expense, of keeping its surface polished would be very great. The same objections apply to the glass cover. The one used by M. Mouchot was in one piece, similar to the glass domes used to cover statuettes and other ornaments. If it were possible to make such a cover of considerable dimensions, its great cost and fragility are sufficient to preclude its use, and, as M. Mouchot admits, it is indispensable to the working of the apparatus. It is true, as M. Mouchot says, that an iron framework, with panes of glass, could be used; but such a cover could not be made air-tight, on account of the tendency of heated iron to expand, which would break the glass. I have tried a glass cover in an octagonal iron frame, and the glass invariably breaks at a temperature of 2,000 degrees Fahrenheit, in consequence of the expansion of the iron. The breaking of the glass by the expansion of the heated air is prevented by the iron disc on which it stands being perforated with holes. As heated air ascends, there is no loss of temperature by these air-vents at the bottom, but it is necessary that the sides and top should be hermetically closed. This is difficult, as there is no substance, that I am aware of, that can be used as solder that will not be fused by the heat. Directly the glass cover in an iron frame used by me in my experiments was exposed to the focus of solar rays reflected from a combination of flat glasses, the lead melted and ran down the joints; the other substances used as cement were burnt away; and as soon as the iron became red-hot the glass cracked. The equatorial motion required by the apparatus, to ensure the solar rays falling in lines parallel to the sides of the cylinder, is another serious objection, when the great weight of a steam boiler of seven or eight horse power, and the additional weight of the glass

cover and metallic reflector are considered. These objections, taken together, must ever prevent M. Mouchot's ingenious invention from being used on a much larger scale than that of the apparatus exhibited in the court-yard of the Public Library of Tours—that is, an apparatus of 8 feet 8 inches in diameter, driving an engine of half-horse power, so that his boast of having successfully solved the problem of concentrating solar heat, as a substitute for fuel, is premature.

The above considerations will enable the reader to judge of the probability of the success of Professor Rohlf's undertaking to drive steam locomotives, by means of solar heat concentrated by revolving burning-glasses, "on a railway line to be constructed across the desert of Sahara." The "burning-glass" proposed to be used is precisely the conical reflector above described.

M. Mouchot, and other writers on the concentration of solar heat by reflection, are unanimous in agreeing that metallic reflectors are superior to silvered glass. I believe this to be a mistake. I think that whatever material reflects light best will be found to be the best reflector of solar heat. However this may be, metallic reflectors can only be superior to glass when highly polished, and the labour and expense of polishing them, almost daily, would be very great where a large area of reflecting surface is required. In using a combination of flat mirrors, which, as I hope to convince the reader, is the only way to concentrate solar heat for useful purposes on a large scale, metal is impossible on account of its cost, its weight, and the daily expense and labour of keeping it polished; whereas silvered glass is cheap, is unalterable by the effect of the weather, and requires, comparatively, scarcely any cleaning. Whilst

writing these lines I have before me, in the compound* of my bungalow† in Bombay, a combination of 480 flat glasses, fixed in sixteen rectangular frames, driving a steam engine at a uniform pressure of 50 lbs. to the square inch. They have reflected the solar rays upon the steam boiler nearly every day for a fortnight without being cleaned, except that the guano deposited on them by the crows has been once or twice removed. During this period they have been exposed in the open air day and night. To test this silvered glass, I placed a large piece at the bottom of a tub of water a whole night, and exposed it on the roof of my house to the rain and sun for three months during the monsoon,—the rainy season in Bombay,—and it was not affected in the slightest degree. A piece of this silvered glass, 2 feet × 18 inches, and one-tenth of an inch thick, was submitted to the following severe test, in order to ascertain its endurance of heat:—It was inclined at an angle of about 45 degs. under a frying-pan, in the shade, and the solar rays from two of my compound mirrors (which will be described) were directed on it so as to transmit the reflection to the bottom of the pan. The temperature was over 600°, which the glass endured for the time necessary to cook the chops in the frying-pan, and it was not affected by the heat in the slightest degree. These silvered glasses, 2 feet × 18 inches, cost in Europe 19*s.* 3*d.* per dozen. The experiment was not made with a view of advocating the above method of frying meat, but in order to ascertain whether it could be so cooked, and also whether the glass would be affected by intense heat. These facts, I submit, fully establish the superiority of glass, as a reflecting material, over metallic reflectors.

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* *Anglicè:*—Court-yard or garden. † House.

CHAPTER V.

BUFFON'S OBSERVATIONS—SOLAR RAYS NOT PARALLEL —BURNING OF THE ROMAN FLEET—PEYRARD'S TELESCOPES—LEONHARD DIGGES, AND NAPIER OF MERCHISTOUN — VILLETTE'S MIRRORS — TSCHIRNHAUSEN'S LENSES—BERNIERE'S LENSES—PARKER'S LENSES.

An account of the powerful effects of concentration of the solar rays, by refraction through biconvex glasses and by reflection from concave mirrors, is given in the *Encyclopædia Britannica*, article Burning-Glasses; as well as some general information on the subject of concentration, which will be useful for my purpose. I recommend those who feel an interest in the subject to read the entire article. The perusal of the article was suggested to me by H. H. Sir T. Madhava Rao, K.C.S.I., the Prime Minister of the State of Baroda, in one of several letters which he wrote to me on the subject of my experiments, in which he took great interest.

Buffon tried, by experiment, the powers of different plane surfaces in reflecting the solar rays, and found that silvered glass was the best reflecting material. If this were otherwise, it would be found that silvered glass is the only reflecting material that could be used on a large scale, by reason of its comparatively trifling cost.

He also found that the solar rays reflected to distances of 100, 200 and 300 feet, from flat glasses, lost scarcely any of their intensity of heat by the thickness of the mass of air which they had traversed. Peyrard makes

some calculations, founded on Buffon's observations, which show that the heating effect of reflection from flat glasses diminishes in proportion with the distance. He calculates that, with a glass of 18 inches in diameter, the rays are so diffused as to reduce the heating effect to one-half at 66 feet, to one-third at 118 feet, to one-fourth at 161 feet, to one-fifth at 200 feet, and to one-tenth at 348 feet. The experiments that I have made go to show that this calculation is approximately correct; but—and this is a very important point—this apparent progressive reduction of heat is in proportion to, and in consequence of, the increase of the diameter of the reflection; the total quantity of heat, however, is nearly the same as when the reflection was close to the glass. The total quantity of heat reflected can only be decreased by the quantity absorbed by the solid matter which the solar rays have encountered in passing through the atmosphere; therefore, in heating a steam boiler, or other object, so long as the reflection does not exceed in area the object, so long as every ray strikes on the object, the effect is the same; because the total quantity of the heat of the reflection has not been diminished, but the intensity, in any part of the reflection, has. The rays have not been diminished in number, but have spread. This can be proved by placing the blackened bulb of a thermometer in the focus of a magnifying glass; whilst the focus is no larger than the bulb, the mercury will remain at the same temperature, but it will descend the moment it exceeds the bulb in diameter, because some of the rays go past it; and will continue to descend as the diameter of the focus is increased, either by increasing or diminishing the distance from the glass, until, when the diameter of the focus is the same as that of the lens, the heat will be less than that of the direct rays of the

sun by the quantity absorbed by the glass. All the mystery of concentration lies in reflecting as many solar rays as possible on the object to be heated. Descartes, and all other opticians, believed and held that there was some mysterious power in the effect of concentration, and could not understand that the degree of heat entirely depended on the number of rays brought to bear, precisely as two bushels of coal produce more heat than one. Solomon de Caux held the same erroneous opinion as Descartes, as is shown by his proposal to add to the heat of his copper vessels by concentrating the solar rays on them through a number of small burning-glasses. So did Buffon, as is evident from his proposal to heat salt pans by twelve flat glasses; and so also did M. Babinet, as is proved by his proposal to cook food by biconvex glasses. Professor Rohlfs and the French *savans* who propose to drive railway locomotives through the desert of Sahara* "by concentrating the solar rays upon the

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* *Apropos*, a rival project to that of constructing a railway line through the desert of Sahara is to restore it to its former condition of a vast inland sea, by letting in the Atlantic on one side and the Mediterranean on the other. It is stated that there are no engineering difficulties in the way of the accomplishment of this grand idea, but such as may be easily surmounted, with no very great expenditure of money and labour. Before, however, commencing to cut the channels which are to effect such a transformation, I should recommend the enterprising projectors to consider how the flooding of the desert of Sahara may affect other parts of the world, and in particular I would recommend the attention of all patriotic Swiss to the point. I would particularly recommend them to consider a passage which occurs in Büchner's work on "Man, in the Past, Present and Future." Büchner is the author of several philosophical works of great repute, *inter alia* "Force and Matter," "Physiological Pictures," "Six Lectures on Darwin," "Essays on Nature and Science," so that considerable weight may be attached

boiler by means of gigantic burning-glasses," perhaps entertain the same erroneous idea, though they probably think of using M. Mouchot's conical reflector.

In science, as in religion, there are certain received opinions and beliefs, to dissent from which is heresy.

In Buffon's time it was an established belief that the

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to his opinion. His work on Man, moreover, is entitled "A Popular Account of the Results of Scientific Research as regards the Origin, Position, and Prospects of the Human Race." So that the passage, which I am about to quote, perhaps expresses the opinion of the majority of scientific men. If so, "the prospects of the human race," as regards that part of it located in Switzerland, may be seriously affected by converting the desert of Sahara into an inland sea. The passage occurs at page 40 of Dallas's translation; (London: Asher & Co., Bedford Street, Covent Garden, 1872):—

"The beautiful Switzerland, so favoured by all tourists and lovers of nature, was then inaccessible to the human foot;—from the summit of the Alps to beyond the Jura down to Geneva and even to far distant Soleure, it was buried beneath the chilling pressure of an enormous mass of ice, which bore upon its mighty back gigantic fragments of rock, and rolled them along to places where they now look as if they had been transported by the hands of giants. The great desert of Sahara was still overflowed by the waves of the sea; its desert and burning sands were not yet exposed so as to produce that glowing wind which, now-a-days, after traversing the Mediterranean, melts away the winter snows on the summits of the Alps as if by magic, and converts the plain of Switzerland, formerly buried under everlasting ice, into a blooming country covered with towns and villages."

This passage deserves attention. If the supposition that Switzerland is only prevented from being "buried under everlasting ice" by the glowing wind heated by the burning sands of Sahara be true, it is evident that it would be better, at any rate for the Swiss, that the Sahara should remain as it is. To re-convert the sea of Sahara into a desert might present greater engineering difficulties than to convert the present desert into a sea.

heat from a large focus of solar rays was no greater than from a small one, provided the diameter of the respective foci was in the same proportion to that of the respective lenses. According to this theory, the heat from the focus of a circle of solar rays thirty-two inches in diameter would be no greater than that from a circle of three inches. Buffon, at first, shared the prevailing opinion :—" Still, however, he had a suspicion that the effect of a large focus might be greater than the mere effect of concentration, although this was contrary to the received opinion of Descartes and other opticians ; and on appealing to actual experiment he found his suspicions satisfactorily confirmed. On trying, for example, a small burning-glass three inches in diameter, the focal distance six inches and the diameter of the focus one-eighteenth of an inch, with a glass thirty-two inches in diameter and a focus two-thirds of an inch, in the focus of the latter copper melted in less than a minute, while in that of the former the copper would scarcely be gently heated."

Considering that the area of the large lens was over 804 inches, and that of the small lens less than 8 inches, one can scarcely understand how the opinion of Descartes and his school could have been entertained, yet we see that Buffon himself only had a "suspicion" of the unsoundness of the doctrine till he proved it by actual experiment.

In the course of Buffon's experiments with flat glasses a curious fact was observed, namely, that whatever shape the glass might be, whether square or triangular, or any other, the same was the figure of the reflection at short distances, but, as the distance increased, the figure became rounded at the angles ; as the distance further increased the angles became still more rounded, until at

last the figure became a circle. This is explained by Buffon by ascribing it, "justly," as the writer of the article says, "to the circumstance of the apparent magnitude of the sun, every portion of the glass reflecting in reality an image of the sun, and the whole reflection being composed of an infinite number of such images, each of which subtends an angle of half a degree. At small distances, therefore, the images are too small, in proportion to the magnitude of the figure, to affect the shape. As the distance increases, the magnitude of each of the images increasing along with it, while the figure and magnitude of the whole reflection remains in other respects the same, the former becomes at last equal to the latter, and the square or triangular figure is absorbed in that of the circular image of the sun, and every glass comes at last to give nearly the same figure."

This explanation is, to me, I confess, entirely unintelligible. The true reason of the reflection from a flat glass being exactly the same shape as that of the glass at a short distance, and assuming a circular shape at a greater distance, lies in the fact that solar rays are not parallel, and that they consequently spread, or diverge, from the point of departure. I discovered the peculiarity, and the reason of it, before reading the article on Burning-Glasses in which it is mentioned. It has nothing whatever to do with reflection. The same peculiarity is observed in the direct rays of the sun coming through a rectangular opening, a window for example; the angles, at a short distance, are sharp, and they become rounded as the distance increases, till the patch of sunlight, which, at a short distance, was of the same shape as the window, assumes the form of a perfect circle, the area of which is considerably greater than the area of the window. The larger the aperture is,

the greater is the distance required for the circular form to be assumed. Few rooms in houses are large enough for the solar rays entering through a window to assume a circular form. I have before me a wooden lattice through which the sun shines in the afternoon, the apertures in which are square, and the wooden bands by which they are divided are exactly as broad as the apertures. The solar rays coming through this lattice form, on the wall facing it, a figure of a number of circles defined by faint lines. The circles overlap each other, and the scarcely perceptible lines are the diminished shadows of the wooden bands. This is a clear proof that solar rays are not parallel, and explains the reason why the figure formed by the reflection of solar rays from a flat glass increases in area and assumes a circular form at a distance from the glass.

The writer of the article on Burning-Glasses does not perceive this. He considers that solar rays are parallel, and is consequently puzzled to account for the diminution of effect by distance. He says—"Were the reflected image to enlarge itself regularly in receding from the glass, and the light to be equally diffused over the image, the calculation could be simple ; but this is not the case, seeing there are rays proceeding from every point of the glass *parallel to one another*, and the effect of which, therefore, does not increase with distance."

The explanation lies, as I have said, in the fact of the rays *not* being parallel to one another. Were they parallel, a house could be burnt on the island of Elephanta by the reflection of fifty flat glasses standing on Malabar Hill, and a whole army might be exterminated during a summer's campaign, by the solar rays reflected from a few looking-glasses, without the operator ever coming within range of its guns.

In Peyrard's edition of the works of Archimedes, the translator suggests several ingenious methods by which the reflection of a large number of flat mirrors might have been concentrated on one spot, and the Roman fleet set fire to off Syracuse, all of which have the faults of being too intricate and complicated to be practicable. I will mention my theory, which has the merit of being simple and practicable. Let us suppose that Archimedes borrowed, say 1000, of the flat steel mirrors used by the ladies of Syracuse, and then ranged 1000 soldiers on the ramparts, each armed with one mirror, and directed them to cast the reflection from every mirror as near as possible upon a selected point of the admiral's or any other vessel; the vessel being painted, pitched, and tarred, and dried by the sun, ignition would have been instantaneous in any spot where fifty of the 1000 reflections were united. The vessel once ignited, the attention of the Syracusans could have been directed to another vessel, and then to another, till the whole fleet was in flames. Every man in the ship, moreover, would have been blinded the moment he looked up to see what was the matter, which it would be his first impulse to do. By this simple plan, solar rays could not only be concentrated on a vessel in sufficient numbers to ignite it, but a focus could be kept on it in its efforts to escape; whereas, by the plan proposed by Anthemius, the point of intersection could only be at a given distance, a few yards from which would render the concentration perfectly innocuous. This discomfiture of the Roman fleet by such novel and startling means, if it really occurred, must have afforded exquisite enjoyment to all present except the Romans. Believing that solar rays were parallel, I had hoped to have repeated the experiment of Archimedes if a hostile fleet ever visited

the harbour of Bombay; but since my discovery that nature acts in defiance of the opinions expressed by Descartes and other opticians, by not ruling the solar rays in parallel lines, I have been compelled to relinquish the idea. Solar rays can never be concentrated for use, as a military weapon, except for distances under half a mile.

Peyrard, believing in this theory of the solar rays being parallel, proposed a plan by which they might be directed and concentrated upon an enemy's vessel with accuracy, to any distance within the horizon. He would have a large number of plane mirrors, each furnished with a telescope, adjustable in such a manner that, being turned to any object, the reflected rays from the mirror should fall in the same direction. The adjusting apparatus consists of a telescope attached parallel to the sides of a mirror, and capable of turning on its axis and carrying the mirror round with it. The mirror is, besides, capable of turning on an axis of its own, perpendicular to that of the telescope, and by this double motion the adjustment is effected. The mirror is first turned on the axis of the telescope until its own particular axis becomes perpendicular to the plane of the incident and reflected rays; and this is done by observing when the shadow of the edge of the frame of the mirror falls on a particular point, marked on an index projecting from the telescope. The mirror is then turned on its own axis until the angle of incidence becomes equal to the angle formed by the mirror and telescope, and this is known by a shadow made through an opening in the silver of the mirror falling on a particular spot in the index. In this manner one operator can adjust all the mirrors entrusted to him with accuracy and facility, and without knowing at all what the other

operators are doing. As far as I have been able to ascertain, Peyrard never destroyed any fleet by this ingenious contrivance. He did not, in fact, go beyond theory, which theory was based on the erroneous opinion that solar rays travel in parallel lines. The curious may see a drawing of this proposed apparatus in Vol. V. of the *Encyclopædia*, and may read Peyrard's detailed description in Vol. VI., 8th edition.

Leonhard Digges, in his work entitled *Pantometria*, published in London in 1571, and republished by his son in 1591, refers to the concentration of solar rays. In the preface to the second edition his son says:—

"Archimedes also (as some supposed), with a glasse framed by revolution of a section parabolical, fired the Roman nauie in the sea, comming to the seige of Syracusa. But to leave these celestial causes, and things done of antiquitie, long agoe, my father hath at sundrie times, by the sunne beames, fired powder and discharged ordnance *half a mile*, and more distante; which things I am the boulder to report, for that there are yet living diverse witnesses of these his doings (*oculati testes*, eye-witnesses); and many other matters far more strange and rare, which I omit as impertinent to this place."

In the twenty-first chapter of the first book the subject of burning-glasses is resumed:—

"Some have fondly surmised that Archimedes burned the Roman nauie with a portion of a section parabolical, artificiallye made to reflect and unite the sunne beames a great distance off, and for the construction of this glasse, toke great peins with high curiositie, to unite large and many intricate demonstrations; but it is a mere fantasie, and utterly impossible with any one glasse, whatsever it be, to fire anything only one thousand paces off, no, though it were an 100 foote over; marry true it is, the parabola, for his small distance, most perfectly doth unite beames, and most vehemently burneth, of all other reflecting glasses. But how by application of mo glasses to extend this unitie or con-

course of beames in his full force, yea to augment and multiply the same, that the farder it is carried the more violently it shall pearse and burne. *Hoc opus hic labor est*, wherein God sparing life and the time which opportunitie serving, and minde to impart to my countrymen some such secrets, as hath, I suppose, in this our age been reveled to very few, no lesse seruing for the securitie and defence of our naturall countrey, than surely to be marvailed at of strangers."

Digges, in the passage above quoted, could have only had in his mind a combination of flat mirrors. His theory was also based on the supposition that solar rays are parallel. Napier's reference to the subject is contained in the first and second items of a list of—

"Secret inventions, profitable and necessary in these days for the defence of this island, and withstanding of strangers, enemies of God's truth and religion.

"*First*, The invention, proof and perfect demonstration, geometrical and algebraical, of a burning mirror, which receiving of dispersed beams of the sun doth reflect the same beams altogether united and concurring precisely in one mathematical point, in the which point most necessarily it engendereth fire. What an evident demonstration of their error who affirm this to be made a parabolic section! The use of this invention serveth for the burning of the enemy's ships, at whatsoever appointed distance.

"*Secondly*, The invention and sure demonstration of another mirror, which receiving the dispersed beams of any material fire or flame, yieldeth also the former effect, and serveth for the like use."

Napier died without revealing his secret. Being pressed, a short time before his death, "not to bury such excellent inventions in the grave," he replied, "that for the ruin and overthrow of man there were too many devices already framed." The words "invention, proof and perfect demonstration, geometrical and algebraical," go to prove that Napier's invention was nothing more

than a theory which had never been tested by experiment, based probably on the belief that solar rays are parallel. When people profess to be able to give geometrical, mathematical, and algebraical proof of a proposition, it is a strong presumption that they are not quite sure of their fact.

The most celebrated concave metallic reflectors that have been constructed were those of Villette, a French artist of Lyons, and that of Baron Tschirnhausen; and the best refractors are those of Bernières, and the lenses made by Parker, an optician of Fleet Street. Buffon also succeeded in making concave mirrors by bending glass upon a convex mould.

Villette constructed five concave metallic mirrors. One was sold for 1,500 livres; another was bought by Tavernier and presented to the king of Persia; a third was sent by the French king to the Royal Academy; the fourth was bought by the king of Denmark; and the fifth was brought to England for public exhibition. The first was 30 inches in diameter, and weighed about a hundredweight (112 lbs.). Its focal length was about three feet, and the focus was about the size of half a *louis d'or* (half an inch). It was mounted on a circular steel frame that could be put into any position. It was made in 1670, and having been brought to St. Germain's, by order of the king of France, his majesty was so well pleased with it, that he rewarded Villette with a hundred pistoles for the sight of it, and afterwards bought it and placed it in the Royal Observatory of Paris. The heat of the solar rays concentrated to a focus in this reflector is shown by the following list of results:—

A small piece of pot iron was melted in ... 40 seconds.
A silver piece of money, fifteen pence, was
pierced in....................................... 24 ,,

	Seconds.
A thick nail, worn by peasants in their shoes	30
The end of a sword blade burnt in	43
A brass counter was pierced in	6
A piece of red copper was melted in	42
A piece of quarry stone was vitrified in ...	45
Watch-spring steel melted in	9
A gun flint-stone was calcined and vitrified in	1
A piece of mortar was vitrified in	52

Green wood and other bodies were ignited instantly. One of Villette's mirrors was brought to England and handed to Dr. Harris and Dr. Desaguliers, who made several trials of it. It was a composition of copper, tin and glass, and its reflection had something of a yellow cast. There were only a few small flaws in the concave surface, but there were some holes in the convex side, which was polished. The diameter of the mirror was 47 inches, its radius of curvature 76 inches, and its focal length 38 inches. The following results were obtained in June 1718, between nine and twelve o'clock in the morning; the time was measured by a half-second pendulum :—

	Seconds.
A red piece of Roman patera began to melt in	3
and was ready to drop in	100
A black piece of the same melted in	4
and was ready to drop in	64
Chalk taken out of an echinus spatangas filled with chalk, only fled away in	23
A fossil shell calcined in	7
and did no more in	64

	Seconds.
The black part of a piece of Pompey's pillar melted in	50
And the white part in	54
Copper ore, with no metal visible, vitrified in	8
Slag or cinder of the iron work said to have been wrought by the Saxons was ready to run in	$29\frac{1}{2}$

The mirror now became hot and burned with much less force :—

	Seconds.
Iron ore fled at first, but melted in	24
Talc began to calcine at	40
Calculus humanus was calcined in	2
And only dropped off in	60
The tooth of an anonymous fish melted in	$32\frac{1}{2}$
Asbestos condensed a little in	28
A golden marcassite broke and began to melt in	30
A silver sixpence melted in	$7\frac{1}{2}$
A King William's copper half-penny melted in	20
and ran with a hole in it in	31
A King George's half-penny melted in ...	16
and ran in	34
Tin melted in	3
Cast iron in	16
Slate melted in	3
and had a hole in	6
Tin melted in	4
and had a hole and was vitrified through in	80
Bone calcined in	4
and vitrified in	33

An emerald was melted into a substance like turquoise

stone; and a diamond that weighed four grains lost seven-eighths of its weight.

The concave metallic reflector made by Baron Tschirnhausen was made of copper plate one-sixteenth of an inch thick. It was according to one account five feet, and according to another four and a half feet, in diameter. The diameter of the focus is not mentioned. The following were its effects:—

1. A piece of wood held in the focus flames in a few moments, so that a fresh wind can hardly put it out.
2. Water applied to the focus in an earthen vessel immediately boils, and the vessel being kept there some time it evaporates all away.
3. A piece of tin, or lead, three inches thick, melts away in drops as soon as it is put in the focus, and when held there a little time is in a perfect fluor, so that in two or three minutes it is quite pierced through.
4. A plate of iron or steel becomes immediately red-hot, and soon after a hole is burnt through it.
5. Copper, silver, &c., melt in five or six minutes.
6. Stones, bricks, &c., soon become red-hot.
7. Slate becomes red-hot, but in a few minutes turns into a fine sort of black glass.
8. Tiles which had been exposed to the most intense heat of fire melt down into a yellow glass.
9. Potsherds that had been much used in the fire melt into a blackish-yellow glass.
10. Pumice stone melts into a white transparent glass.
11. A piece of a very strong crucible melted into glass in eight minutes.

12. Bones were converted into a kind of opaque glass, and a clod of earth into a yellow or greenish glass.

If these wonders were effected, as is stated, by concentrating the solar rays falling upon a circle of 5 feet in diameter to a circle of $\frac{1}{2}$ an inch in diameter, would not a circle of 25 feet in diameter have a proportionately greater effect? Suppose this question answered in the affirmative, and the information added that the question is an idle one, because it is impossible to make a concave reflector larger than 5 feet in diameter, the reply is—True, but a combination of flat mirrors can be made not only equal in area to a circle of 25 feet, which has an area of 490 square feet, but equal to a circle having an area of 4900 square feet, or any greater area that may be desired; these flat mirrors cost less than 6*d*. per square foot; they are, with ordinary care, everlasting, and the solar rays reflected from any number can be united to a focus and kept upon a boiler, or other object, of about four feet square, from sunrise to sunset.

The first burning lenses of any considerable magnitude were constructed by Tschirnhausen. Two of these, a large and small one, were used together, the pencil of rays refracted through the large lens being passed also through the small one, by which means the diameter of the focus, which, if the large lens only were used, would have been one and a half inch in diameter, was reduced to eight lines. By using this small glass the intensity of the heat of the focus was increased in consequence of the diameter being reduced, but the total quantity of the heat was considerably diminished, *i.e.* by the considerable quantity absorbed by the small lens. If, for example, a substance as large as, or larger than, the focus of the large lens were to be heated, the object would be effected better by

removing the small lens altogether: *e. g.* water in a small vessel would have boiled sooner in the focus of the large lens only, because there would have been a larger quantity of heat, though of less intensity than if the pencil of rays had passed through both lenses.

The large lens, which weighed 160 pounds, was purchased by the Duke of Orleans, and presented by him to the French Academy. The following effects were produced:—

1. All sorts of wood, whether hard or green, and even when wet, were burnt in an instant.
2. Water in a small vessel boiled immediately.
3. All the metals, when the pieces were of a proper size, were easily melted.
4. Tiles, slates, delf ware, pumice stone, talc, whatever their size, grew red and vitrified.
5. Sulphur, pitch, and resins melted under water.
6. When the metals were placed in charcoal they melted more readily, and were completely dissipated.
7. The ashes of wood, vegetables, paper, and cloth were converted into a transparent glass.
8. All the metals were vitrified upon a plate of porcelain. Gold received a fine purple colour.
9. Substances that would not melt in pieces were easily melted in powder; and those that resisted the heat in this form melted on adding a little salt.
10. A substance easily fused assists in melting more refractory substances when placed with them in the focus; and it is very singular*

* I fail to see anything "singular" in this. The substance that first becomes molten communicates its heat to the other in

that two substances which are very difficult to melt separately are very easily melted when exposed together, such as flint and English chalk.

11. A piece of melted copper being thrown suddenly into cold water produced such violent concussion that the strongest earthen vessels were broken to pieces, and the copper was thrown off in such small particles that not a grain of it could be found. This did not happen to any other metal.
12. All bodies except the metals lose their colour. The precious stones are instantly deprived of it.
13. Certain bodies vitrify easily and become as transparent as crystal; but by cooling they grow as white as milk and lose all their transparency.
14. Other bodies that are opaque when melted become beautifully transparent when cooled.
15. Substances that are transparent both when melted and cold become opaque some days after.
16. Substances which the heat renders at first transparent, but which afterwards become opaque by being melted with other substances that are always opaque, produce a beautiful glass, always transparent.

Bernière's lens was a hollow glass filled with seventy quarts of spirits of wine. It consisted of two spherical

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addition to the heat of the focus. The latter, already on the point of fusion, suddenly becomes bathed in the liquid fire of its molten companion.

segments eight feet radius and eight lines thick. The lenticular cavity was four feet in diameter, and six inches and five lines thick at the centre. The focal length of a zone at the circumference, about six or seven lines broad, was ten feet and six lines; the focal length of a portion at the centre, about six inches in diameter, was ten feet seven inches and five lines; the diameter of the focus was fourteen lines and three-fourths. When the whole surface was covered except a zone at the circumference of six or seven lines, the following were the foci of the different rays:—

	Feet.	Inches.	Lines.	
Violet......	9	6	4½	from the centre of the lens.
Blue	9	7	10½	
Yellow ...	10	2	3	
Orange ...	10	2	10	
Red.........	10	3	11½	

The following experiments were made in October 1774, in the *Jardin de l'Infante,* by MM. Trudanie, Macquer, Cadet, Lavoisier, and Brisson, the Commissioners appointed by the Academy:—

1. The burning power of the anterior half of the lens was much greater than that of the exterior half.*
2. On the 5th of October, after midday, the sky not being very clear, two farthings placed upon charcoal were completely melted in half a minute.
3. In order to melt forged iron it was found neces-

* What can be meant by the anterior and exterior half of a convex lens? And how could it be ascertained which half possessed the greatest burning power?

sary to concentrate the rays by a second lens, which concentrated the rays to a focus of eight lines in diameter.

4. In the focus of the small lens, upon a piece of hollow charcoal, small pieces of forged iron were placed, which were instantly melted. After fusion the metal bubbled up and fumed like nitre in fusion, and then sent off a great number of sparks. This effect (which was observed during the experiments with Tschirnhausen's lens) always took place after the fusion of iron, forged iron, or steel.

5. In order to try the effect upon greater masses, pieces of forged iron and the end of a nail were exposed to the focus, and were melted in fifteen seconds. A piece of nail five lines long and one-fourth of a line square, which was added to the rest, was instantly fused; and the same was the case with a screw that had a round head and was eight lines in length.

6. Some days afterwards a bar of steel, four inches long and four lines square, was exposed so as to receive the focal image in the middle of its length. This part was completely melted in five minutes, after having begun to run at the end of the second minute.

7. Platina, in grains, appeared to draw together, diminish in bulk, and to prepare for fusion. A little after it bubbled up and smoked. All the grains were united into one mass, without, however, forming a spherical button, like other melted metals. After the platina had undergone this semi-fusion, it was not attracted by the magnet, as it was before the operation.

8. A portion of platina, deprived of the iron which it contained, and therefore not affected by the magnet, lost a part of its bulk, smoked and formed one mass, which was extended under the hammer.
9. Several experiments were made in order to find the lens that was most proper for collecting the rays after refraction by the large lens. A spirit of wine lens two feet in diameter and four feet focus, a solid lens eighteen inches in diameter and three feet focus, and another thirteen inches in diameter, were successively tried, but none of them produced such a powerful effect as the lens eight inches and a half in diameter and twenty-two inches and eight lines focus, though it was full of vesicles and striæ.

The astonishment expressed by these scientists at the fact of a lens of eight and a half inches in diameter "collecting the rays, after refraction by the large lens," better than a lens two feet in diameter, and the fact that no one has attempted to explain the reason, show how very little was, and apparently is, known of the principle of the refraction of solar rays. MM. Trudaine, Macquer, Cadet, Lavoisier, and Brisson, the Commissioners who were appointed by the Academy to make the experiments mentioned, would have been still further astonished if they had tried a lens of only four inches in diameter. They would have found that the effect would have been greater than that obtained from the lens of eight and a half inches. After the solar rays have been refracted through a large lens, a small lens is more effective than a large one, intensifying the heat of the pencil of rays by contracting the diameter of the focus; not because it "collects" the rays better, but because it diminishes the heat less, by absorbing less

rays than a larger lens would absorb. According to Sir John Herschel, 184 calorific rays out of every 1000 are absorbed by very thin glass, and a larger number in proportion as the glass is thicker. The smaller, therefore, the lens that is interposed between the large lens and the point of intersection, the more effective the result.

In Parker's celebrated lenses the same error is committed. He passes the rays refracted through his large lens through a smaller lens of sixteen inches in diameter, and $1\frac{5}{8}$ inch thick in the centre. If he had used one of six or eight inches in diameter, the effect would have been, for the reasons I have stated, greatly increased. His large lens was two feet eight inches in diameter when fixed in its frame, and $3\frac{1}{4}$ inches thick in the centre, and weighed 212 pounds. It concentrated the rays to a focus of one inch in diameter without the small lens, but when the rays were passed through the small lens they were concentrated to half an inch. The small lens weighed 21 pounds, and the whole apparatus, including frame and fittings, cost Parker £700. The following are the results of experiments reported by Major Gardner and several members of the Royal Society :—

Substances fused, &c.	Weight in grains.	Time in seconds.
Common slate	10	2
Scoria of wrought iron.	12	2
Gold, pure	20	3
Platina, do.	10	3
Nickel	16	3
Cast iron, a cube	10	3
Silver, pure..............	20	4
Crystal pebble	7	6
Terra ponderosa, or barytes...	10	7
Lava	10	7
Asbestos	10	10

Substances fused, &c.	Weight in grains.	Time in seconds.
Steel, a cube	10	12
Bar iron, do.	10	12
Garnet....................	10	17
Copper, pure	33	20
Onyx	10	20
Zeolites	10	23
Pumice stone	10	24
An Oriental emerald ...	2	25
Jasper	10	25
White agate	10	30
Flint, Oriental	10	30
A topaz or chrysolite...	3	45
Common limestone ...	10	55
Volcanic clay	10	60
Cornish moor-stone ...	10	60
White rhomboidal spar.	10	60
Rough cornelian.........	10	75
Rotten stone	10	80

A diamond of ten grains, when exposed to the lens for thirty minutes, was reduced to six grains. It opened, foliated, and emitted whitish fumes, and when again closed it bore a polish and kept its form.

Gold retained its metallic state though exposed for many hours.

The specimens of platina were in different states of approach to a metallic form. Copper did not lose any of its weight after an exposure for three minutes.

Iron steel shear melted first at the part in contact with the charcoal, while the other part exposed to the focus was unfused.

Iron scoria melted in much less time than the turnings of iron.

Calx of iron from vitriolic acid precipitated by mild

fixed alkali weighed five grains before exposure, and five and a quarter after it.

The remains of regulus of zinc, after it had melted and was nearly evaporated, were magnetic. It was not pure.

Regulus of cobalt was completely evaporated in fifty-seven seconds.

Experiments were tried with other substances, the results of which it is unnecessary for me to mention. I have cited these wonderful results from concentration from a small area of reflecting or refracting surface in order to induce the reader to reflect on the probable results of concentration upon a larger scale. I now propose to show how easily, and at what little cost, concentration can be effected on a large scale by a combination of flat silvered glasses of common sheet glass, costing less than sixpence per square foot.

CHAPTER VI.

A CALCULATION OF THE CUMULATIVE POWER OF CONCENTRATION—NO POINT AT WHICH ACCUMULATION CEASES—KIRCHER'S EXPERIMENT REPEATED—EXPERIMENTS WITH FLAT GLASSES—MY COMPOUND MIRRORS—THE FIRST STEAM ENGINE EVER WORKED IN INDIA BY SOLAR HEAT—THE MARQUIS OF WORCESTER'S EXPERIMENT REPEATED, BY SOLAR HEAT—THE PLAN FOR KEEPING THE FOCUS ON THE BOILER—PROPOSED NEW BOILERS—SEVERAL PURPOSES TO WHICH SOLAR HEAT CAN BE APPLIED.

We have seen, in the preceding chapter, the great intensity of heat that is produced by concentration of solar rays, by refraction through a biconvex lens, or by reflection from a concave mirror. In Parker's lens the rays falling on a circle of two feet eight inches in diameter, concentrated to a circle of half an inch in diameter, produced a temperature of 71,680 degrees Fahrenheit, in which every substance was either melted or vitrified in a few seconds. A cube of cast iron, for instance, weighing ten grains, was melted in three seconds. Concave mirrors have greater power of concentration than biconvex lenses, by reason of the great proportion of calorific rays the latter absorb. As it is impossible to make either a concave reflector or a glass lens of more than a few feet in diameter, and as, if it were otherwise, their great cost would prevent them from being used (Parker's lens cost £700, and concave metallic reflectors are quite as dear), neither of these articles can be ever used for concentration of solar rays on a large

scale. I will use them here for the purpose of estimating the intensity of heat that would be concentrated by concave mirrors and biconvex lenses, if it were possible to construct them of large dimensions.

The intensity of heat concentrated by a circular lens, or reflector, is quadrupled when the diameter is doubled, because the area of a circle increases as the square of the diameter. That being so, and Parker's lens of two feet eight inches in diameter producing a focus of 71,680°, it is clear that a lens of

5 feet	4 in.	in diameter	would produce	...	286,720	deg.
10 ,,	8 ,,	,,	,,	...	1,146,880	,,
21 ,,	4 ,,	,,	,,	...	4,587,520	,,
42 ,,	8 ,,	,,	,,	...	18,350,080	,,
85 ,,	4 ,,	,,	,,	...	73,400,320	,,

and so on *ad infinitum*. By interposing a smaller lens between the large lens and the focus, on the plan followed by Parker and others, the rays from a lens of 85 feet in diameter could be collected, and the diameter of the focus diminished, to half an inch.

If we now take this focus of ½ in. in diameter and 73,400,320° temperature, produced by a lens 85 feet 4 inches in diameter, and increase the diameter up to 32 inches, either by increasing or diminishing the distance, we get a temperature of 17,920° Fahrenheit, as shown by the following figures:—

Diameter of focus	½ inch—	Temperature..		73,400,320	deg.
,,	1 ,,	,,	...	18,350,080	,,
,,	2 ,,	,,	...	4,587,520	,,
,,	4 ,,	,,	...	1,146,880	,,
,,	8 ,,	,,	...	286,720	,,
,,	16 ,,	,,	...	71,680	,,
,,	32 ,,	,,	...	17,920	,,

A focus of 32 inches in diameter having a temperature

of 17,920° would, there can be no doubt, if directed on to the water space of a steam boiler, soon bring a large quantity of water to ebullition; but it is impossible, as we have seen, to construct concave mirrors or glass lenses of sufficient dimensions to produce such a focus.

But a combination of flat mirrors can be fixed in frames, on the principle suggested by Anthemius of Tralles, Kircher, Buffon, and Oliver Evans, not only to concentrate the solar rays from an area of 85 feet 4 inches in diameter of reflecting surface, but from an area equal to that of Leicester Square in London, or Elphinstone Circle in Bombay. There is no limit whatever, in fact, to the extent to which solar heat can be concentrated by a combination of flat reflectors, fixed in rectangular frames as shown by the drawing in page 81, and as there is no mechanical difficulty in keeping the focus upon an object, such as a steam boiler, from sunrise to sunset, and as moreover the reflecting material costs not more than £2-10 per horse-power, and cannot be injured except by breaking or excoriation, which can be prevented by ordinary care, the problem of the utilization of solar heat is conclusively solved by a combination of flat mirrors.

M. Mouchot, therefore, in rejecting flat mirrors, as offering "*peu d'intérêt au point de vue des applications*," and in insisting, as he does, on the superiority of metallic reflectors over silvered glass, has been looking in the wrong direction for the solution of this important problem, and persistently casting aside, as useless, the only means by which success could have been assured. His apparatus, in consequence of its enormous cost, can never be anything more than an ingenious model or toy. I have succeeded in solving the problem by rejecting what he pronounces to be indispensable, and by using what he considers to be useless.

The accuracy of the figures by which I have proved that a concentration of the solar rays falling on a circle of 85 feet 4 inches in diameter, to a focus of half an inch, would give a temperature of 73,400,320° Fahr., and that that focus, when enlarged to 32 inches in diameter, would have a temperature of 17,920°, may perhaps be disputed on the following grounds:—I find it laid down in the *Encyclopædia Britannica*, in the article on Burning-Glasses, that there is a point at which the accumulation of heat ceases in consequence of radiation, the heat dispersing, it is said, into the surrounding atmosphere as fast as it is received. This theory is as absurd as it would be to say that a volume of water is not increased by the junction of two rivers, because of the increased evaporation. If there is any truth in the theory, it would be interesting to know how the fact was ascertained, and also the point at which this dispersion, equal to the accumulation, commences. By the writer's own showing it must be at a point above 71,680° Fahrenheit, because that is given as the temperature of the focus of Parker's lens. In the same article, however, the writer quotes Buffon to the effect that there is less loss by radiation, in proportion, from a large focus than from a small one:—" Even with the same degree of concentration, the effect of a large focus will be much greater than that of a small one: the small focus operating in a very narrow space and dispersing the heat rapidly into the surrounding mass, there is little left for accumulation, the heat increasing as the *square* of the diameter, whilst the dispersion only increases *as* the diameter; much more remains to accumulate in the centre. The central portion of the large focus being surrounded by a zone almost as hot as itself, much less dispersion will take place, and the temperature will consequently be higher."

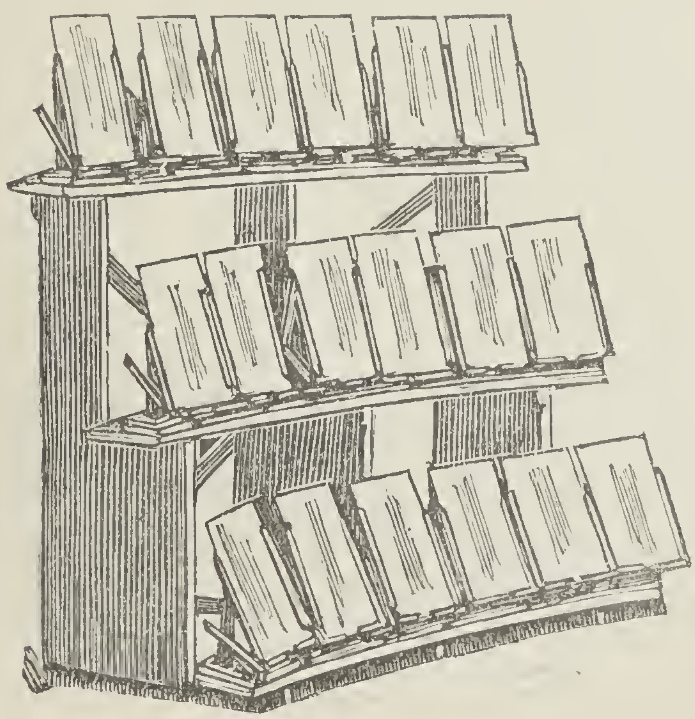
This theory, of there being a point at which accumulation ceases, through dispersion, has never been submitted to the test of experiment, and, consequently, is worthless; but, if it were well founded, it is, at least, consoling to know that the dispersion commences at a temperature above 71,680°; that it is less, in proportion, from a large focus than from a small one; and that, therefore, if a focus of several feet in diameter can be produced, the dispersion equal to the accumulation will not begin till after a temperature has been attained of 71,680°.

The above data and calculations thoroughly convinced me of the practicability of driving stationary steam engines by solar heat reflected from flat glasses, before proceeding to test it by experiment. It was clear also that silvered glass, whether inferior or not to polished metal as a reflecting material, was the only material that could be used, in consequence of its comparatively trifling cost. Ericsson, in the fragment of his letter which I have quoted, has furnished some data on which to calculate the important point of expense. He estimated that an area of a hundred superficial feet of reflecting surface (ten feet square) was more than equivalent to one horse-power, and I find that a hundred feet of silvered glass would cost less than £2-10. I commenced my experiments then with fair prospects, that amounted almost to a certainty, of success.

My first experiment was to repeat that of Kircher. Suspending a thermometer, with a blackened bulb, against a whitewashed wall, I reflected upon it the solar rays that came in through a chamber window. I used, at first, one flat glass only, and I found that the mercury, which stood at 80° Fah., rose to 102°, in ten minutes. I then added the reflection from a second glass, and the thermometer rose to 124° in ten minutes.

A third reflection, in less than ten minutes, raised the mercury to 140°, beyond which the thermometer was not constructed to register. This increase of 22° per each reflection was the highest that I have ever obtained. It confirmed me in my theory of the practicability of driving steam machinery by solar heat by means of flat glasses. It seemed clear to me that, at this rate of increase, 1000 reflections would give a focus of over 20,000°.

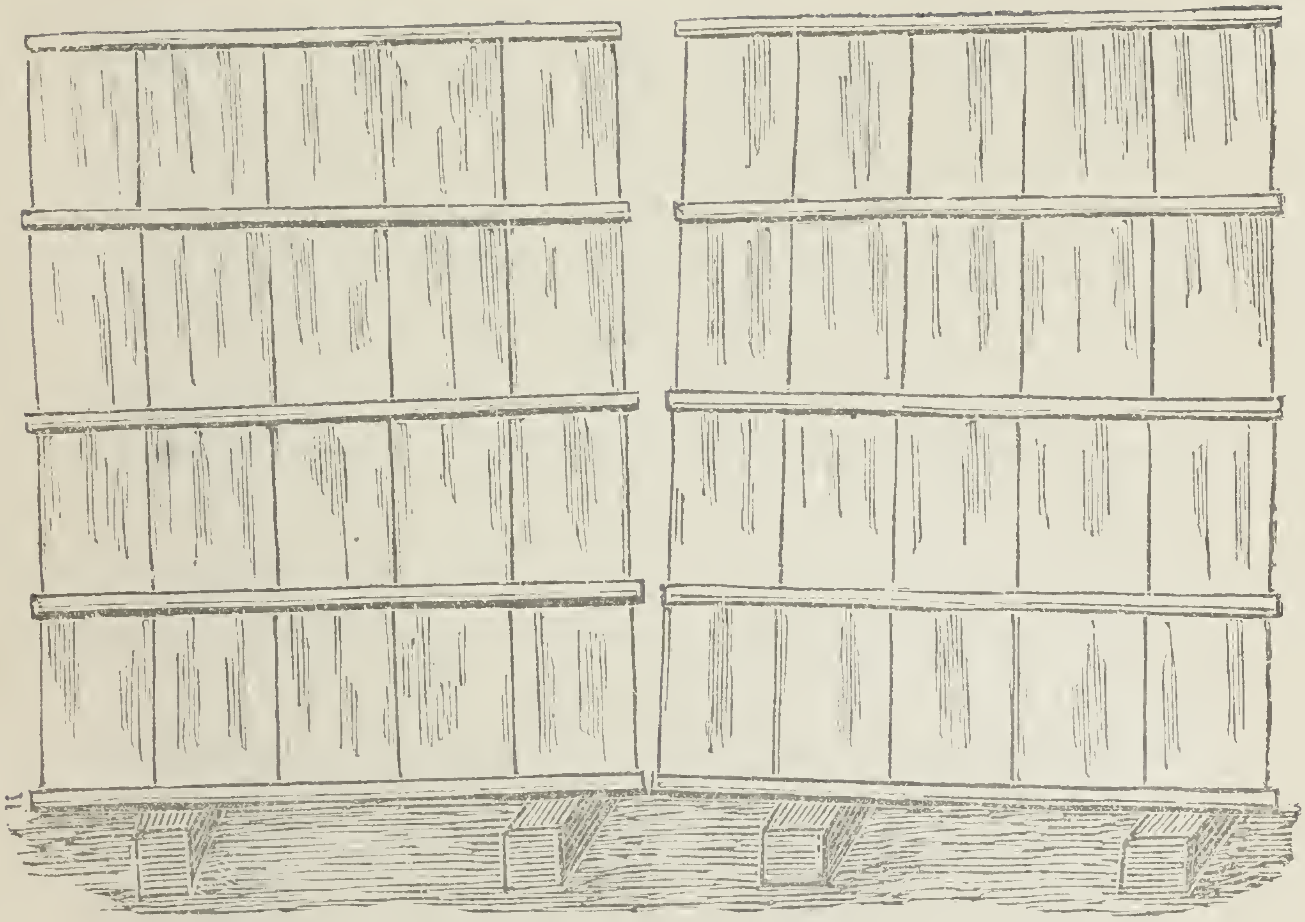
I found, however, that in the open air and the reflection at a greater distance—20 feet—the increase per each reflection was considerably less than 22° Fah. On trying eighteen glasses, each 17 inches × $10\frac{1}{2}$, upon another thermometer, which professed to register up to 700°, I only obtained 360°. Deducting 90° as the initial temperature, (the thermometer was shaded from the direct rays of the sun,) this gave an average of 15° for each reflection. The eighteen glasses used in this experiment were ranged upon wooden shelves in three tiers of six in each tier, as shown in the next drawing.



Each glass was moveable on a swivel in the same manner as an ordinary toilet glass, and also upon a pivot driven through the foot of the frame, so that it had a universal motion by which the reflection could be directed on any object, and to any distance, by a touch of the finger. I had four sections of 18 each, such as that shown in the drawing. Each section of 18 gave a focus of 360°. Two sections, = 36 glasses, made the mercury in the thermometer boil, leaping up to over 670°. When the four sections, = 72 glasses, were united, it is fair, I submit, to suppose that the temperature of the focus was then over 1140°. A copper cylinder containing three gallons of water, placed in the focus, boiled in exactly twenty minutes. Wood ignited immediately, without being, as in Buffon's experiment, previously smeared with tar and shreds of wool.

With 42 small glasses, each six inches by four, reflecting the solar rays on a small boiler holding a pint and a half of water, provided with a steam pipe, steam was got up, in 20 minutes, by 8 A.M., in Bombay; and at Poona in the Deccan, in 15 minutes.

The plan followed in the experiments above described, of having only a single flat glass fixed in one frame, has the advantages that the reflection from each glass can be directed on any object, at any distance, and that the reflections can all be accurately united into one focus, so as to give precise data; but such accuracy is unnecessary when all that is required is to heat a steam boiler at a distance which never requires to be altered. Time and labour will therefore be saved by placing a large number of flat glasses in rectangular frames in the manner shown in the following drawing:—



The above is a drawing of two compound concave mirrors, each formed of 20 flat glasses, each glass 9 inches by 6 inches, placed in four rows of five glasses in each row. I made them of these small dimensions in order to serve as models, to illustrate an essay upon the subject of the utilization of solar heat, which I submitted to the Committee of the Sassoon's Institute of Bombay, in March 1878, in competition for the medal or prize given annually by the Institute for the best essay, or the best new and useful invention, for which the Committee awarded me the gold medal of the Institute. The mirrors are curved lengthways and breadthways so as to form the segment of a hollow sphere of 24 feet in diameter, so that the reflections from the 20 glasses intersect at a distance of exactly 12 feet. The focus is about a foot in diameter and of a maximum temperature of about 300°, in addition to the temperature of the atmosphere, but varying according to the period of the day and the clearness and stillness of the

air. By my plan, 32 of these mirrors, in four tiers of eight in each tier, could be brought to bear upon a boiler placed at a distance of 12 feet from the centre mirror, *i.e.* 32 foci of a foot in diameter, each having a temperature of 300°.

I have 16 others of larger dimensions, varying from 6 feet by 4 feet to 6 feet by 3 feet 4 inches. The glasses are slid into grooves cut in the bands across the frame. Each of these large compound concave mirrors is curved so as to form a segment of a hollow sphere of 40 feet in diameter, the focus, about two feet in diameter, being exactly at 20 feet distance, and the maximum temperature of the focus about 360°, exclusive of the temperature of the atmosphere. Seven of these mirrors were tried on a cylindrical boiler, of copper, one-sixteenth of an inch thick, having a diameter of 16 inches and a height of 2 feet 7 inches, holding 9 gallons of water. The water boiled in exactly 30 minutes, and after exactly one hour of ebullition, it was found that $3\frac{3}{4}$ gallons had been evaporated.

In this experiment, as well as in all that I have made before sending this book to press, the mirrors did not have fair play, as the boilers were all of less diameter than the foci, instead of being, as they should have been, of twice the diameter of the foci; consequently a very large portion of the solar rays reflected from the glasses was wasted. The reason of this apparently foolish mistake was that I had had the boilers made to be covered with a glass cover and used with M. Mouchot's conical reflector, before I had conceived the idea and become convinced of the superiority of a combination of flat glasses; and as copper boilers are expensive, I tried my experiments with the material I had on hand before deciding on the kind of boiler that would be best adapted to receive the heat from solar rays.

The boiler used in the next experiment I had had

made in England on the same principle as that of M. Mouchot. It was of the same dimensions outwardly, but the annulus of water was 3 inches in diameter instead of 3 centimêtres, so that, leaving the same room for steam space as his, my boiler held 12 gallons against his 20 litres (about $4\frac{1}{2}$ galls). It was made of beaten copper $\frac{1}{4}$ of an inch thick, and was, therefore, the strongest boiler in the world of its dimensions, 2 feet 7 inches high and 18 inches in diameter. As, in the account of M. Mouchot's apparatus given in the *Revue des Deux Mondes* of 1st May 1876, it was stated that his boiler being only three millimêtres thick, and the pressure obtained being 5 atmospheres, *i.e.*, 75 lbs., the experiment had to be discontinued for fear of an explosion, I ordered mine to be made $\frac{1}{4}$ of an inch thick and of beaten copper, to the astonishment of the boiler-maker, who, in answer to my inquiry, whether there was any fear of an explosion, said he "should think not!" Had he shown the slightest hesitation on this important point, I should have told him to make it half an inch thick. Amateur engineers cannot be too cautious. Twelve gallons of water were poured into this boiler and the solar fire turned on it, at 7-30 A.M.; at 8 A.M. there was a pressure of 10 lbs. and at 8-30 a pressure of 70 lbs., when the safety valve opened. A gentleman present kept the valve down by placing his foot on it, till the steam, escaping from several leaks in the joints of the fittings, made the position untenable. The weight on the safety valve was then supplemented by a brick suspended from the lever by a piece of string, when suddenly the packing and red lead at the top of the dome under the socket of the steam pipe (which had been fixed by my butler, who professed to have formerly been a fitter) gave way, and, with a terrific noise, the whole volume of steam

rushed out of the opening. On turning off the solar rays and examining the boiler it was found to be dry. All the water had either been evaporated or blown out.

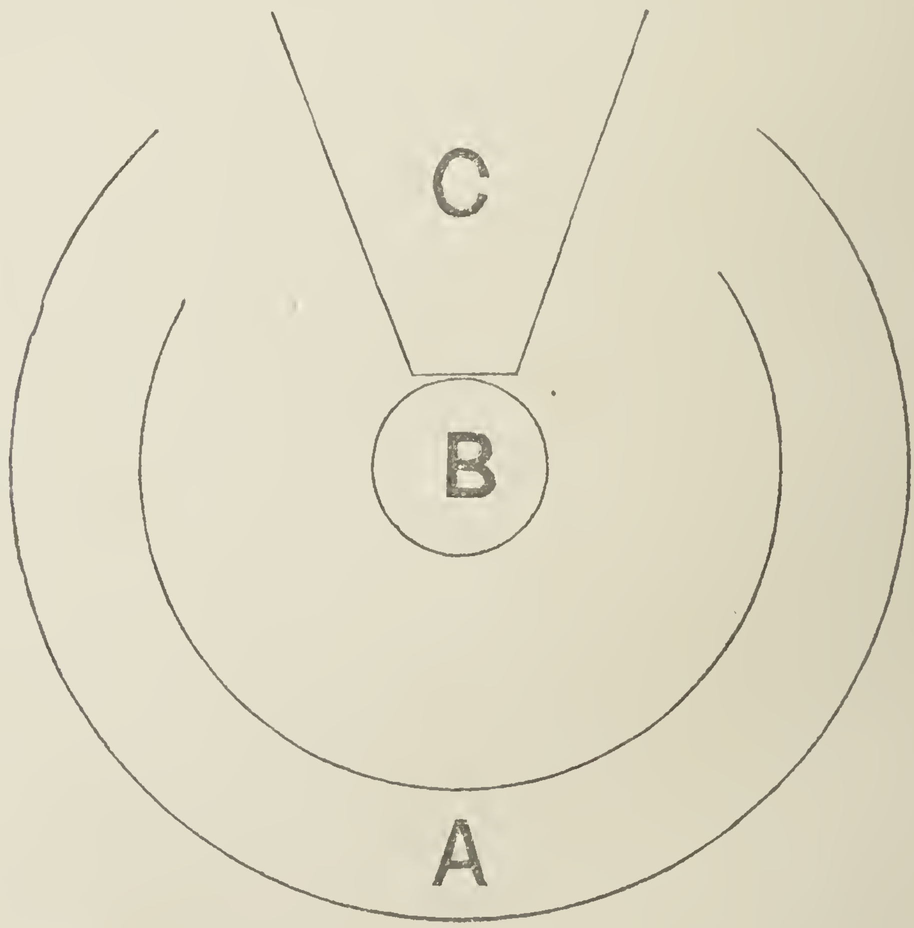
When this boiler had been properly fitted up, by professional fitters, a steam pump was hired, said to be of $2\frac{1}{2}$ horse-power, and it was connected with the steam-pipe. At 7-30 A.M. fire was opened on the boiler from the whole battery of 16 mirrors, at a range of 20 feet, the boiler containing 12 gallons. At 7-45, *i.e.* a quarter of an hour, there was a pressure of about 2 lbs., and at 8-30 A. M. 55 lbs. The steam was then turned into the cylinder of the pump, and the pump was kept working at a uniform pressure of about 30 lbs. to the square inch.

This pump, the first steam engine ever worked in India by solar heat, was kept going daily, for a fortnight, in the compound of my bungalow at Middle Colaba, in Bombay, and the public was invited, by a notification in the daily papers, to witness the experiments. Amongst those who witnessed some of these experiments were His Excellency the Commander-in-Chief Sir Charles Staveley, General Schneider, Colonel Merriman of the Royal Engineers, the Acting Secretary to Government in the Public Works Department for the Presidency of Bombay, the Hon'ble Mr. Justice Pinhey and Mr. Pinhey, Sir Mungaldás Náthubhoy, Mr. Morarji Gokaldas, one of the principal Mill-owners of Bombay, and a large number of professional engineers and steam-users and other members of the European and Native communities. I mention the above names and the fact that a large number of gentlemen resident in Bombay was present, in order to show that my statements can be corroborated by witnesses.

The following experiment was made, at the suggestion of an engineer, in order to ascertain whether a larger quantity of water could be boiled by my 16 mir-

rors than the boiler would hold. It was the experiment made by the Marquis of Worcester, in 1663 I think, with the first steam boiler ever used in England, suggested to him by the inventor, Solomon de Caux, in his book *Les Raisons des forces mouvantes, avcc diverses machines tants puissantes qu'utiles,* which the Marquis obtained from him when visiting him in the Bicêtre, where the unfortunate author had been confined, as I have said, by the order of Cardinal Richelieu, as a lunatic, as he would persist in declaring that machinery could be moved by the force of the steam of boiling water,—a clear proof, in the cardinal's eyes, of lunacy. An open cask, containing 20 gallons of water, was placed by the side of the boiler, and an additional length of pipe was added to the steam pipe and introduced into the cask till it reached within two inches of the bottom. The steam in the boiler, which was at a pressure of 60 lbs., was then turned into the cask till the indicator had run down to zero. Steam was again got up to 50 lbs. and again turned in, when the water in the cask boiled, and continued boiling, with great violence, the steam continuing at a uniform pressure of about 10 lbs. Here we have 32 gallons of water boiling violently by the heat of solar rays concentrated upon $\frac{2}{3}$ of the outside of a metal cylinder one-fourth of an inch thick. The half pint of water boiled by Baron Tschirnhausen and the four and half gallons by M. Mouchot, are the only other instances of water being boiled by solar heat that are recorded, except that referred to in Ericsson's letter to his friends in Sweden, which I have quoted, but in which neither the quantity of water, nor the plan by which he concentrated the solar rays, is mentioned. My 32 gallons of water compare favourably with Tschirnhausen's half pint and M. Mouchot's four and half gallons.

The plan by which the foci are kept upon the boiler, from shortly after sunrise to a little before sunset, is by moving the mirrors four or five times during the day towards the East, until, at sunset, they nearly face the position they occupied in the morning. This is effected by having a circular tramway upon which the mirrors can be moved, as shown in the following drawing, to surround the boiler for three-fourths of a circle, leaving a space for the engine, or engine room, on the South, or at that point of the compass over which the sun appears to pass in its apparent diurnal course during the greatest portion of the year, which will either be South or North. In Bombay it will be the South.



A is the ground and platforms on which the tiers of mirrors stand, and are moved, as shown in the drawing at page 79. B is the boiler, and C the engine or the engine room. The engine or engine room can be brought up close to the boiler, and, if necessary, the fittings of

the boiler, steam gauge, water gauge, &c., can be led into the engine room through the wall, or, if the engine is in the open air, through a sheet of metal, which will serve as a shield for the man who attends the engine.

The services of one man would be sufficient for each tier of mirrors, but I would have an additional man to assist the man in charge of each tier, alternately, in moving the mirrors, so as to allow them to indulge in turns in the pastime of sitting down, of which the natives of this country are so fond. The mirrors would not have to be moved more than three or four times during the day. In the experiments I have described they frequently reflected the rays on the boiler from 7-30 A. M. till 12 noon, without being moved; but of course the area of reflecting surface is somewhat diminished by obliquity; so that, to have the advantage of their full power, it would be better to move them slightly every hour, so as to keep the centre mirror opposite the sun; but the point is not of so much consequence as one would think. Of course at mid-day, for a short period, when the planet is at, or near, its meridian, the position of the tiers of mirrors is of no consequence —the solar rays could then be directed upon a boiler in the centre from a complete circle of mirrors, if necessary, instead of a segment of one-third of a circle.

The way in which steam boilers are heated by ordinary fuel is by currents of heated air which pass through tubes circulating through the water and finally pass out with the smoke through the flue. In order to utilize as much, and waste as little, as possible of the heat generated by the combustion of the fuel, it is made to heat an immense surface of metal, in the shape of a large number of metal tubes, which absorb a portion only of the heat as it rushes along, and communicate it to the water. The best multitubular boiler cannot utilize more than a

portion of the heat that is generated. A large quantity must escape by the flue, and be wasted. For this reason boilers have to be made of an immense bulk as compared with the quantity of water they contain. What with the space required for the fire grate, the flue, and the tubes, less than half the area of the boiler is occupied by the water.

In boilers heated by solar rays, on the contrary, there is no heated air excepting the small quantity that radiates from the outside of the boiler, and is dispersed into the atmosphere; and this only takes place, to any appreciable extent, after the heat has performed its work of boiling the water. The luminous rays of the sun are transformed from light into heat by contact with an opaque body, which, in this case, is the shell of the boiler, so that every unit of solar heat is utilized by absorption into the metal, on which the rays beat, like missiles, in a continuous and incessant storm of solar fire, penetrating into the metal, like fire from a blowpipe, and the heat is thence communicated to the water. The solar heat thus accumulates in the metal as water accumulates in a lock. There is consequently no occasion for tubes or chambers for heated air, the metal being heated and not the air; and, therefore, a boiler heated by sunbeams need be of no more than half the bulk of a boiler heated by ordinary fuel.

The construction of a boiler best adapted for being heated by solar rays opens a field for the ingenuity of inventors. Several suggestions have been made to me, all more or less ingenious and impracticable, but all, unfortunately, providing for the circulation of heated air through chambers or tubes, for which, as I have said, there is no occasion, because there is no heated air to be circulated. The objects to be kept in view are, to apply the heat round and under the bottom of the boiler where heat is most effective, to have a large heating surface,

and to guard against the waste of any of the solar rays. The boiler that I used in my last experiments was double the thickness required. Being only sixteen inches in diameter, and the foci to which it was exposed being two feet in diameter, supposing every focus had struck it fair in the centre, which was not the case, a space of about eight inches of each focus was wasted. Being only two feet seven inches in height, *i. e.*, only seven inches higher than the diameter of the foci, the boiler was covered by the solar fire to its whole height owing to the foci not being accurately adjusted; and frequently the fire bricks on which it stood were illumined by the foci to the depth of a foot. Not more than three-fourths of the boiler, moreover, was enveloped by the rays. Yet, notwithstanding these faults, 32 gallons of water—*i.e.*, 12 gals. in the boiler and 20 in the cask—were kept boiling by reflecting material costing £7-14, quite half of which was wasted, and the other moiety badly applied, upon a boiler constructed on a wrong principle. The boiler to be heated by solar rays must be of at least twice the diameter of the foci brought to bear on it.

I have imagined two descriptions of boilers, either of which will, I believe, have more than quadruple the effect of that produced on the boilers I have hitherto used. They are contrary to all the recognized principles for the construction of boilers, and, therefore, excite only the merriment of professional men, because they do not provide chambers or tubes for the circulation of heated air, and have no contrivance for the prevention of radiation. The facts, that there is no heated air to circulate and very little radiation to prevent, are not considered as reasons.

The first is a thin annulus of water, at the bottom of a cylindrical boiler, of a very large diameter in proportion

to its height, with a circular opening through the annulus equal in diameter to one-fourth the circumference of the boiler; the bottom of the shell, containing the main body of the water above the annulus, coming below the top of the aperture and sloping from it. By this arrangement every inch of the bottom of the water is exposed to a large surface of hot metal. There is one objection to it, however, namely, that for the aperture to be opposite the mirrors throughout the day the boiler will have to be moved on its axis nearly half a circle; and I am told that it is a mechanical impossibility to effect this, and, at the same time, to preserve the connection with the steam engine and the feed pump.

The next is an annulus of water open at the top. I conceived this idea through seeing two finger glasses one smaller than the other. The water lying between these two glasses, outside the small one and inside the large one, would, it is evident, be heated almost instantaneously, if the foci from the top tier of mirrors were made to strike on the inside of the annulus, and those of the bottom tier on the outside. I am convinced that this is the kind of boiler the best adapted for being heated by solar rays that can be invented, because every inch of the metal is exposed to and penetrated by a storm of solar heat which it communicates to the water. I should have been able to have tried this boiler, and to have recorded the result in this book, but for the despatch of the contingent of native troops from Bombay, which made it impossible for me to get it ready, as every ironsmith in the island was required for making tanks, &c., for the expedition, and all the iron was in requisition. The boiler was to be at the top four feet in outside diameter, two feet eight inches in inside diameter, the bottom three feet four inches in diameter, and the height three

feet. The breadth of the annulus at the top would thus be eight inches, which would decrease in breadth as it descended till the two sides met at the bottom. This boiler, which we will call the heater, would be connected with another boiler by one or more tubes, the bottom of the second boiler being on a level with the top of the heater : the level of the water being kept considerably above the level of the water in the heater. The steam will be generated in the second or upper boiler, and, as it is not intended to concentrate any solar rays upon it, radiation can be effectually prevented by coating it with LeRoy's non-conducting composition, which prevents radiation better than a casing of bricks or any other means. There being no tubes, chambers, fire grate, or flue in this boiler, it would contain a solid cylinder of water, and its bulk would consequently be very small in comparison with ordinary boilers of the same capacity. When eight foci of 300 each are directed on the inside of this annulus, and the same number on the outside, every unit of heat penetrating the metal, not a single ray being wasted, and scarcely any radiation taking place till after the water has been heated, I expect that ebullition will take place almost instantaneously.

Not being able, as I have said, to get this boiler made in Bombay of the above dimensions, and of quarter-inch wrought sheet iron, I am trying to get a small one made on the same principle, of one-sixteenth inch iron ; but I fear it will not be ready for trial before this goes to press, as the book is already in type as far as I have written. This small boiler will be thirty inches in outside diameter at the top, and of proportionate corresponding dimensions throughout to the large one. An experiment with this boiler will determine a very important point, namely, whether iron will do for boilers to be

heated by solar rays. M. Mouchot is clearly of opinion that copper is the only metal that can be used, on account of its being a better conductor of heat than iron. The conducting powers of copper and iron are, respectively, represented by the figures 736 and 119, so that the difference is very great. Ordinary boilers, however, have to be made of iron on account of its comparative cheapness; and, as they answer their purpose, there is no reason why iron should not answer equally well with solar heat. If iron conducts heat more slowly than copper, in revenge it retains it longer; therefore, once heated, less radiation takes place from iron than from copper. But, if it be found that copper is so much better than iron as to compensate for its greater cost, the heater only—*i. e.*, the part of the boiler on which the solar rays impinge—need be made of the more costly of the two metals, and the shell in which the steam is generated may be made of iron.

The result of my experiments with flat mirrors is that I have ascertained, beyond the possibility of a doubt, that, even with an ordinary vertical cylindrical boiler,—the most ill-adapted boiler for the purpose,—stationary steam engines, of any power, can be driven at an expense of £2-10 per horse-power, in India, from 8 A.M. to 4 or 5 P.M., in every day on which the sky is clear. The issue to be determined then is this: whether, having regard to the number of days throughout the year on which the sky is clear, in India, it is worth while to use solar heat as a motive power, either alone or as an auxiliary to ordinary fuel.

I am in receipt of a letter from Colonel Merriman, written, after having witnessed my experiment, at the request of His Excellency Sir Richard Temple, Govern-

or of Bombay, in reply to a letter addressed by me to His Excellency, in which I requested him to depute some officer to examine the matter. Colonel Merriman says that, both before and after having witnessed my experiment, he had consulted several able engineers, who were of opinion, in which he concurred, that solar heat could not be used for purposes on a large scale, such as a motive power for spinning and weaving mills where the working expenses were very great. I have, unfortunately, mislaid his letter and cannot give it *verbatim*. I interpret it to mean that a factory in which a large number of hands are employed, must commence work before the hour at which steam can be got up from solar heat on clear mornings, and that such a factory could not afford to give the workmen a holiday on days when the sky is not clear. In short, that no factory could depend on solar heat alone as a motive power. I have no idea of contesting the truth of this opinion ; but the question is, cannot steam generated by solar heat be used as an auxiliary to, and with, steam generated by fuel? Other engineers are unanimously of opinion that it can. Steam generated by solar heat, they say, could be injected into the ordinary boilers, and every cubic inch of steam so injected would represent a saving of precisely the quantity of coal that would have produced it. If that opinion is correct, steam generated by solar heat can be used as an auxiliary to ordinary fuel, for a considerable portion of the year, from 8 A.M. to 4 P.M. Let us suppose a huge boiler, heated by the solar rays, outside the engine house, with steam up to 80 lbs. pressure : could this not be injected into the ordinary boilers precisely as the feed-water is injected?

There can be only one answer to the question. Every day in which the solar rays are uninterrupted by clouds,

the fires could be extinguished or banked up from 9 A.M. to 4 P.M., and the machinery worked partially, or entirely, by steam generated by solar heat. In a country where coal is imported from England, where the cost of transport renders its use impossible in places removed from the sea coast or a line of railway, and where wood is always dear, and the supply of solar heat is gratuitous and inexhaustible, at least 25 per cent. of the fuel now used could be saved annually by the utilization of solar heat.

Besides the important industries of spinning and weaving, there are several purposes for which steam power is used in India which do not work at all during the rainy season; for instance, ginning and pressing cotton, and raising water for irrigation. A very large proportion of the days on which machinery is worked for these purposes in India are sunny. Machinery for ginning cotton, I am informed, is generally of about 15 or 20 horse-power, requiring a compact little boiler which could be heated with a small number of my compound mirrors. The ordinary steam boiler used for these purposes could be made vertical and placed in the open air. Coated with LeRoy's composition, radiation would be as effectually prevented as if it were encased in brick work. A solar heat-generator placed alongside of it, and connected to it by a tube, would either heat it entirely, or partially, according to the clearness of the atmosphere, and the number of mirrors used, and on cloudy days it could be heated entirely by fuel.

Another purpose for which solar heat could be extensively used in India is, though it seems paradoxical, the making of ice.

Besides driving steam machinery there is the distillation of spirits and potable water, in both of which opera-

tions a large quantity of fuel is used. In Aden, and I believe in the island of Perim, potable water is obtained by distillation from sea-water, or from brackish water drawn from wells dug in the sand below the level of the sea. At Aden there are six condensers in constant work, three worked by Government, and three by private firms, producing from 9 to 12 lbs. of water per 1 lb. of coal. The price of water ashore is Rs. 3 per 100 gallons, delivered in the houses, and Rs. 4 per 100 gallons delivered on board ship. Some time ago a French firm applied to General Schneider, who was in command of the station, for a large piece of ground in order to distil water by solar heat, and, I believe, it was allotted to them. Nothing has been done, however, my correspondent says, "although the machine was said to work satisfactorily in Paris." The "machine" was M. Mouchot's solar apparatus, consisting of a conical reflector of electro-plated copper, a vertical copper boiler covered with a glass cover, and mechanism to keep the apparatus in a position to receive the solar rays parallel to the boiler. No wonder that, when the enterprising projectors who had obtained the grant of this large piece of land, sat down to count the cost of covering their grant of land with a large number of such machines,—for one cannot be made of any considerable size,—they could not proceed any further. To sell water, condensed by such costly apparatus, at a profit, it would have to be sold almost at the price of champagne. With a combination of flat glasses, however, a powerful jet of steam from a solar boiler could be injected into the condenser that is used with the ordinary boiler, and the result would be a saving of, at least, 25 per cent. of the coal now used for the distillation of potable water. At Aden, moreover, there is no lack

of solar heat. Besides distilling potable water there, the bread for the garrison could be baked and the food cooked by solar heat. If ever the place is besieged and the supply of firewood cut off, the fact that the men's food can be cooked by means of their looking-glasses is worth knowing.

It is unnecessary to enumerate all the purposes to which solar heat, concentrated by a combination of flat mirrors, can be applied in tropical countries—they will readily occur to the reader. Among the most obvious, besides those already mentioned, are the fusing of metals; smelting of iron, copper, and other ores; baking bricks, tiles, pottery, &c.; burning of shells and kunkur for the manufacture of lime; the cremation of deceased Hindus and others; and every purpose, in fact, for which heat is used. For all purposes for which very intense heat is required, it is simply a question of the multiplication of glasses, there being no practical limit to the number of reflections that can be used at once. With these facts and data it is clear that solar heat can be generated by reflection from a combination of flat mirrors to a degree of intensity, and to an extent, that has never before been dreamt of. The heat of the fiercest blast furnace in an iron foundry may be described as genial warmth in comparison with the heat that could be generated by reflection of the solar rays from a combination of flat mirrors.

CHAPTER VII.

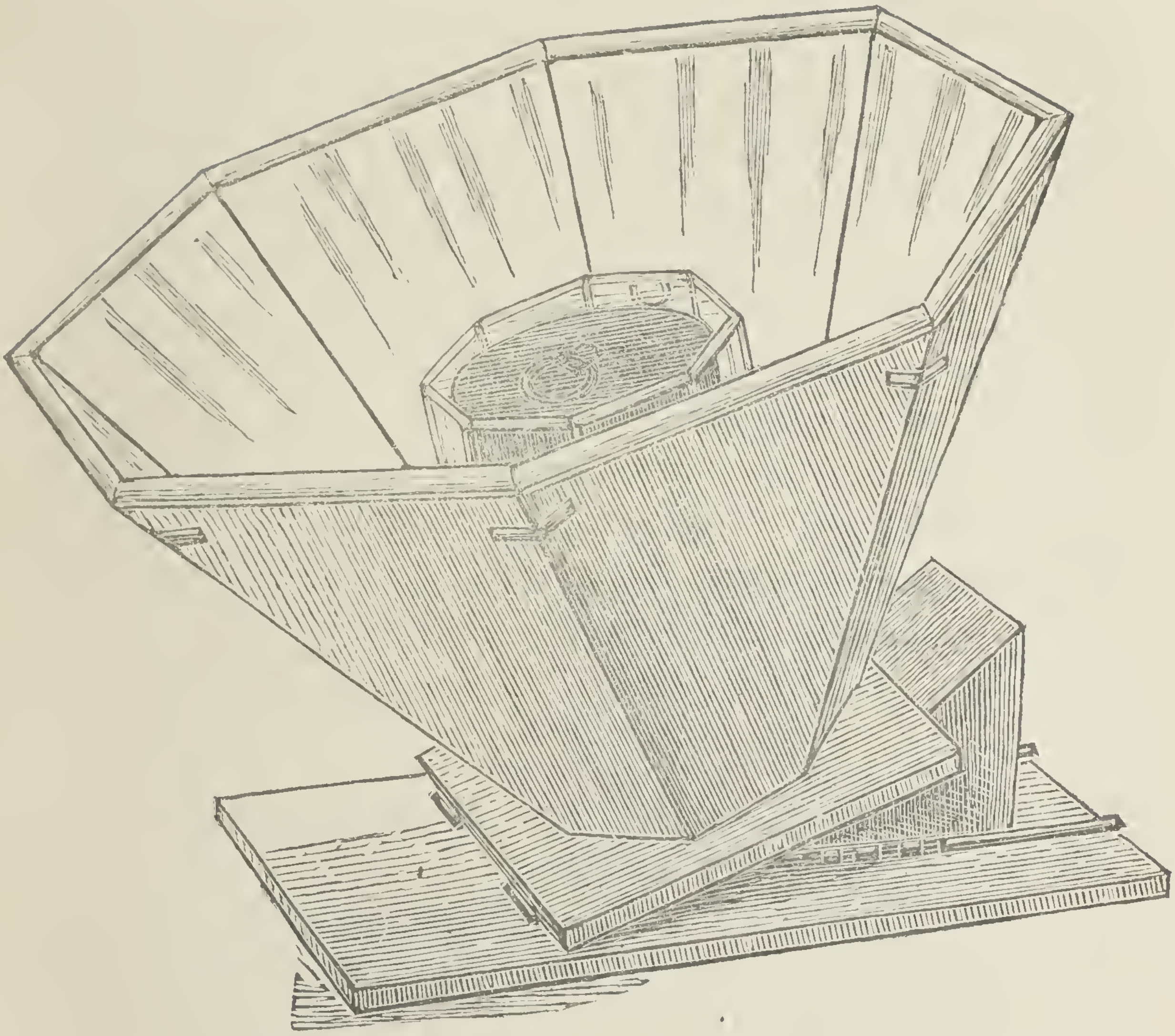
COOKING FOOD—ROASTING MEAT, GAME, &C.—BUTYRIC ACID—SINGULAR PROPERTY OF RED AND YELLOW GLASS—MY APPARATUS—ITS POWER OF RETAINING HEAT—USEFUL FOR SOLDIERS IN THE FIELD, TRAVELLERS, &C.—CAN BE USED ON THE MARCH—ESPECIALLY SERVICEABLE FOR THE SICK AND WOUNDED—USE OF ORDINARY LOOKING-GLASSES—THE *miroir face et nuque*.

If thirty-two gallons of water can be boiled, in a few minutes, by the concentrated rays of the sun, it goes without saying that food can be cooked by the same means. The foci from three or four of the compound mirrors, used by me to heat my steam boiler, would heat an oven in which one could bake bread, pies, &c., and would also cook food contained in metallic or earthenware cooking utensils. I reckon that one of these mirrors, each say six feet by three, would suffice to cook the food of a company of soldiers of a hundred men. To troops in the field, travellers, explorers, missionaries, seamen, and others, in tropical countries, the fact that all kinds of food, but especially animal food, can not only be cooked by the solar rays reflected from their looking-glasses, but that food so prepared will be more nourishing, palatable, and free from impurity than food prepared in the ordinary manner, is one which may be useful for them to know.

We have seen that the authors, from whose works I have quoted, generally entertained the idea that food can be cooked by solar heat, but that they have not taken

any pains to ascertain the fact by experiment. With the exception of the one experiment made by Sir John Herschel, those made more recently by M. Mouchot in France, and those made by myself in Bombay, no one, as far as I have been able to ascertain, has ever attempted to cook food by solar heat. We have seen that M. Mouchot, by means of a copper vessel enclosed in a glass case, heated by a metallic cylindro-parabolic reflector, succeeded in cooking all kinds of food, boiling liquids, and distilling spirits, essences, &c. He also roasted joints of meat, poultry, game, &c. on a spit, in the focus of solar rays from his reflector, precisely as before an ordinary kitchen range. He discovered, or perhaps was aware before making the experiment, that oleaginous matter,—the oily fat of animals,—when exposed to the direct or reflected rays of the sun, was converted into butyric acid, a substance having such an offensive odour and taste as to render the roast unpalatable. He then discovered that a sheet of red, pink, or yellow transparent glass, interposed between the roast and the reflector, had the effect of preventing this fermentation, as those colours have the curious property of absorbing, neutralizing, or eliminating, the rays by which it is caused.

The result of the number of experiments that I have recently made in Bombay, in order to ascertain the best kind of apparatus for cooking food by solar heat so as to combine cheapness and portability, is the apparatus shown in the following drawing.



It is precisely on the principle of M. Mouchot's solar steam boiler. It consists of three pieces,—a cylindrical copper vessel, tinned on the inside and provided with a tight-fitting lid, to contain the food; a transparent glass cover, in the form of an octagon with a flat top, two inches greater in diameter, and five inches longer than the copper vessel. This glass cover is placed over the copper vessel so as to leave a space of one inch above and around, and four inches under the copper vessel. The copper vessel is held firmly in its place by an iron claw which grips it at the bottom like the claw of a bird; and the glass cover is held by four or more small blocks of wood. The third piece is a conical reflector composed of eight pieces of teakwood lined with silvered sheet-glass. It is two feet four inches in

diameter at the large base, ten inches at the small base, and eighteen inches in height. The angle may be any between 45° and 60°. Perhaps the best would be 50°. It is sufficient if the position be changed once every half-hour, or even every hour. The reflector is fixed on to a board which is joined to another board by two hinges, and is kept inclined in the direction of the sun by a wedge inserted beneath it, so that the solar rays fall nearly parallel to the sides of the vessel and glass cover. The vessel thus receives the direct rays of the sun; and, by reflection, every ray passes, in the form of light, through the transparent glass (except the 184 rays out of every 1,000, which, according to Sir John Herschel, are absorbed by the glass), and then, coming in contact with the blackened surface of the vessel, the rays are transformed from luminous rays into obscure heat; the transparent glass, which gives passage to luminous rays, after exacting the toll fixed by Sir John Hérschel, bars the passage of obscure heat as effectually as a sheet of metal would bar it; and it is thus retained as an envelope of hot air round and under the copper vessel. The heat thus retained by the glass is caused by radiation from the copper, and this radiation does not commence till the copper has reached a very high temperature. The glass cover must be, as nearly as possible, air-tight. Air, when heated, expands, and, when cool, contracts, so that the glass cover would be broken by this expansion, or by this contraction, if it were hermetically closed. To prevent this, the disc of iron on which M. Mouchot's glass cover stood was perforated with holes through which the air was forced by expansion or drawn in by contraction. With my apparatus these holes are unnecessary, because the glass cover, merely standing on a piece of wood, the

bottom will not fit so accurately as to prevent the escape or admission of air from the bottom.

I do not claim any superiority for my apparatus over that of M. Mouchot's, except on the score of cheapness, and that mine can be constructed by native artizans in any Indian village from materials to be purchased in any Indian bazaar. His conical reflector was one piece of electro-plated metal, which required constant friction to keep it bright, and his glass cover was a dome, in one piece, such as is used to cover clocks, statuettes, &c. My reflector is composed of a combination of flat mirrors which, in his opinion, is of no practical use, and my glass cover can be made and mended by any native lantern-maker, whilst his, once broken, can never be repaired.

In this apparatus, four or five pounds of meat, with a proportionate quantity of vegetables, placed in the vessel without any water, are thoroughly cooked in about the same period of time as over an ordinary fire. The first trial I made of it was with a neck of mutton, and a quantity of potatoes and green peas. The apparatus was placed in the sun's rays at 10-30 A. M., and was moved slightly every half-hour till 2 P. M. Although it was a cloudy day, the sun being hidden by clouds frequently, at one time for a space of 20 minutes, the *plat* was found, at 2 P. M., thoroughly cooked, and was pronounced, by those who partook of it, to be more tender and palatable than if prepared in the ordinary manner. It is apparent that this must be so when we consider the regular and gradual application of the heat. The quantity of juice that had exuded from the meat and vegetables was so great that people would not believe the fact that no water had been placed in the vessel, until they were subsequently convinced of the truth of it by ocular demonstration.

I do not pretend to say that this method of preparing food will be regularly adopted by Europeans in affluent circumstances, who sit down daily to a dinner consisting of a succession of courses, even if the sun shine every day of the week. This difficulty was forcibly put to me by a friend. "Man cannot live on one dish alone," he said, "you should contrive a number of partitions in your apparatus in which soup, fish, entrées, vegetables, poultry, game, joints, and pastry could all be separately cooked; then you might fairly lay claim to have invented an apparatus for cooking by solar heat." If he had added partitions for making ice-puddings, and cooling champagne and other wines, the apparatus suggested would indeed have been perfection. One other objection, urged by the same friend, I have surmounted. He said—"Sunshine, with your plan, is a *sine quâ non.* Your cook" (he referred to the sun) "goes to bed at six, and civilized people dine at 7-30 or 8 P.M." It occurred to me, on hearing this objection, to ascertain how long the heat would be retained in the vessel after it was withdrawn from the rays of the sun. I therefore had it removed into a room at exactly 4 P.M. and covered with a railway rug, pressed slightly down between the reflector and the glass cover. At 8 P.M., four hours afterwards, the rug and glass cover were removed, when the copper vessel was found too hot to be handled by the naked hand; and the contents, which were passed round and partaken of as an entrée, by a party of eight persons who were at table, were hotter than any of the other dishes. I have not yet taken the trouble to ascertain for how long a period the heat would be retained, but my belief is that it would be found very nearly, if not quite, as hot if served for breakfast next morning. This statement can be corroborated by several people in Bombay, or which is better, by

actual trial. I hold a letter from Surgeon-Major Partridge of the Bombay Presidency, who made several trials of the apparatus. He says that he cooked a leg of mutton in it, and that heat was retained for three hours after removal from the sun's rays. I have similar information from Poona, in the Deccan. There four pounds of meat and a quantity of vegetables were cooked in an hour and forty minutes. This is not merely one experiment like that of Sir John Herschel's; it has been made over a hundred times, invariably with success, at Bombay and Poona. Besides meat and vegetables, rice and grains of all kinds have been cooked in it. At one of a series of lectures, delivered in Bombay upon heat, in the Guzerathi language, by a Parsi gentleman who is, I understand, the first native in Western India who has taken a degree in science, my cooking apparatus was exhibited and explained. The copper vessel was full of rice which had been cooked in it that day, and which was handed round, on plates, to the audience.

I lent one of the apparatus to a corporal belonging to the garrison at Colaba. On returning it he informed me that he had cooked his rations, as well as those of five of his comrades, in it, nearly every day during the Christmas holidays, and that, on every occasion, the food was found far more palatable than when prepared in the ordinary manner. He also baked a Christmas cake in it. All the men belonging to his corps, as well as those of the artillery and other corps stationed at Colaba, witnessed, he says, the performance of the machine with incredulity which soon gave place to astonishment.

I think I have sufficiently explained the construction of this cooking apparatus to enable the reader, with the aid of the illustration, to make one for himself. It is not necessary that my model should be scrupulously adhered

to. If it be borne in mind that the angle of reflection of the solar rays equals the angle of incidence, that a glass cover over a metal vessel admits and imprisons the heat, and that the vessel must rest on wood or any non-conductor of heat, the apparatus can be made by any one. The best angle is, as I have said, 50^0, but any between 45^0 and 60^0 will do.

The apparatus can be used on the march. Placed on a coolie's head the food is not only cooked as he trots along, but the apparatus acts as an umbrella to guarantee his complexion against the ravages of the sun. Carried by an elephant, camel, bullock or any other beast of burden; in a cart, or in a boat or vessel at sea, the food is prepared quite as well as in camp or quarters. This is worth knowing when wounded, sick, or invalids are being carried long distances in a tropical climate. Five or six pounds of meat can be placed on a coolie's head, who accompanies them on the march. At every halt the coolie is arrested, he places his umbrella on the ground, and you extract from it food more nourishing, and better adapted for the sustenance of sick people, than could have been prepared by the *cordon bleu* of a cardinal. The fact that the heat will be retained for hours after sunset, as I have ascertained, and, as I believe, till next morning, is very valuable to medical men in charge of the sick or wounded on the march in tropical countries.*

Moreover, without having anything that may be called an apparatus, it will be sufficient to carry the copper cooking vessel, the glass cover, and say a dozen plates of thin sheet glass each about fifteen inches by ten. Should

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* The apparatus above described is sold by Mr. John Neuberg, Medow Street, Bombay.

the plates of glass be not on hand, and the travellers can muster amongst them half a dozen small looking-glasses, they are perfectly independent of firewood, if they have solar heat as a substitute. The game they have shot, the chickens their servants have procured *en route*, or any other food they may have, is placed in the vessel, the glass cover placed over it, and the solar battery is brought to bear by propping the looking-glasses against stones, or any other support that may be lying about, whilst the travellers repose, in blissful expectation of the delicious and invigorating meal that is being prepared for them. At the short range necessary for cooking food for five or six people, a large number of looking-glasses is not required. You have first the direct rays of the sun playing on the copper vessel. The heat, when it has been absorbed by the copper and begins to radiate, imprisoned by the glass, alone suffices to rapidly raise a temperature, inside the vessel, of nearly 200°. Every reflection obtained in addition to the direct rays of the sun, adds about 22° for each reflection, so that three glasses are sufficient to cook food in about two hours. The greater the number of glasses used, of course, the quicker the food is prepared; but what is gained in time is lost in succulence, as food cooked in the vapour of its own juice should not be cooked too rapidly. There is a three-folding mirror, called, I believe, *miroir face et nuque*, formed of three flat glasses connected by hinges, which is used by ladies of fashion, and others, to enable them to arrange their back hair. This article will, if the occasion arises, serve as an admirable reflector for preparing food by solar heat, if placed round three sides of a cooking vessel covered by a glass cover such as I have described.

CONCLUSION.

Upon the well-recognized principle, that he invents and discovers who proves, I claim to be the inventor and discoverer of the only practicable way of utilising solar heat, on a large scale, namely—by a combination of flat mirrors. The only admissible proof that anything which has never been done, and which is deemed impossible to do, can be done, is the doing it. That proof I have given, by being the first to have driven steam machinery by solar rays concentrated by flat mirrors.

With the exceptions of Archimedes, supposing the feat attributed to him of burning the Roman fleet by flat mirrors to have been really performed by him; of Anthemius, who demonstrated the possibility of it; of Kircher, who suggested flat mirrors; of Buffon, who submitted the theory of Anthemius and Kircher to the test of experiment; and of Oliver Evans, who expressed an opinion that steam boilers could be heated by flat mirrors, which the writer in the *Bulletin de la société d'encouragement* for 1821 considered to be such an *idée singulière*, there is not a single instance on record of any one even imagining the possibility of concentrating solar rays, on a large scale, by a combination of flat mirrors.

M. Mouchot, the first and the only person, with the exception of Ericsson and myself, who has ever used solar heat as a motive power for machinery, only speaks of a combination of flat mirrors to reject it as of no practical use.

Buffon, the only man who is known to have experimented with flat mirrors on a rather large scale, limited

his experiments to 148 glasses, each 8 inches by 6 inches. Supposing he ever used the whole of the 360 which his mirror, wrongly as I contend, is said to have contained,—of which there is no record whatever,—the dimensions of the rectangular frame to contain such a large number of glasses approached the limit to which it is possible to construct such a frame so as to be portable and manageable. The fact that he took the trouble to construct a mirror containing 148 glasses, the largest number with which he ever experimented, not to speak of his alleged construction of a mirror of the prodigious size required to hold 360 glasses, is a convincing proof that he never contemplated the possibility of using more than one of such mirrors at a time. If further proof be wanting it is contained in the fact that he never made mention of such an idea. It is inconceivable that he would have been silent upon a point which is of more importance than all his discoveries upon the concentration of solar heat put together, if the idea, that a large number of such mirrors could be used at one time, had occurred to him. It is unlikely, in my opinion, that he would have been at the pains to construct his mirror holding 148 glasses, which was 7 feet high by 8 feet broad, had he known that four small mirrors, holding each 37 glasses, would have had precisely the same effect as his huge unwieldy mirror of 148; and had he known that the focus from each mirror could have been united into one focus. By my plan of placing the mirrors in rows and tiers, 200 of such mirrors as that of Buffon, or any larger number, could be made to concentrate the solar rays into one focus not much larger in diameter than that of his mirror. Let us calculate the temperature that such a number of mirrors would produce. Placing the heat of the focus of his mirror of 148 flat glasses at 1480°, *i.e.* at 10° per glass, a

very moderate estimate, 200 such mirrors would have given a focus with a temperature of 296,000°. The object Buffon had in view, in constructing his mirror, was merely to settle the question of the possibility of Archimedes burning the Roman fleet with flat mirrors, in the manner suggested by Anthemius and Kircher, and not to ascertain the extent and intensity to which solar heat could be concentrated. As all the wranglers on this historical problem had in their minds one mirror only, and not a combination of mirrors, the idea of more than one did not occur to Buffon.

Oliver Evans, who was the first to suggest that steam boilers could be heated by solar rays, had also only one mirror in his mind. This is clear from the words:—"A large number of mirrors"—*i. e.* of flat glasses—"mounted on the same *frame* and directed on the same point," which could only have heated a boiler of small size.

Ericsson appears to have died without publishing, so far as I know, any description of the solar machines referred to in the fragment of the letter to his friends in Sweden, which I have quoted. There are grounds, however, for supposing that his plan for concentrating solar heat was similar to mine. They are, first, the gigantic scale of concentration which he proposes, which could only be effected by a combination of flat mirrors, and, second, his estimate that a reflecting surface of 100 superficial feet is equal to one horse power, which my experiments have proved to be approximately correct. If this be so, it is only a singular coincidence of two individuals engaged in the same pursuit discovering the same means to attain their object, for all the knowledge I possess of Ericsson's experiments is derived from the fragment of his letter, which I have translated from M. Mouchot's work on solar heat; and all the information on the subject of

the concentration of solar rays that I have acquired has been obtained from M. Mouchot's work, the article in the *Encyclopædia,* my own calculations, and the results of my experiments.

I may, therefore, fairly lay claim to be the first to discover, and to have proved, that there is no limit whatever to the extent to which solar heat can be concentrated by reflection from a combination of flat mirrors; subject to the claim—if any—which Ericsson, if he had lived, might have made.

I have shown that solar heat can be used as a motor for steam machinery for at least eight hours per day, in India, on every day on which the sky is clear.

That less than Ericsson's estimate of 100 feet of reflecting surface is equivalent to one horse power.

That the reflecting material to give one horse power costs less than £2-10, and will last till broken by accident or careless handling.

And that there is no limit to the extent to which solar heat can be concentrated.

With these facts and data, I leave it to practical men to consider whether it will pay to use solar heat, as an auxiliary to fuel, for heating steam boilers; by injecting the steam generated by it into the boilers, or otherwise. To arrive at a finding on this issue, an important point to be considered is the cost of fuel in India. At Bombay, in ordinary times,—where coal is cheaper than at any other place in the country,—coal is about Rupees 18 (£1-7) per ton. The probability of war with Russia has just raised the rate to Rs. 23 (£1-17) per ton; and, if war be declared, it will rise at once, I am told, to Rs. 30 or 35 (£2-5 or £2-14). In the mofussil, at places on one of the lines of railway, the rate increases in proportion to the distance from Bombay in consequence of the great cost, in

India, of railway transport. At Sholapore, in the Deccan, about 250 miles from Bombay, on the Great Indian Peninsular line of railway, where there is a cotton mill belonging to Mr. Morarji Gokaldas, one of the principal mill-owners of Bombay, the mill is worked, he tells me, entirely by firewood. At places distant from a line of railway to which coal would have to be carried in bullock carts, or on the backs of asses, the combustible is unknown, and the large number of machines used for ginning and pressing cotton are fed entirely by firewood. For these two purposes, ginning and pressing cotton, the use of solar heat, instead of effecting only a saving of 25 per cent. of fuel, would save 50 or 75 per cent., because cotton is only ginned and pressed between harvest time and the monsoon,—from December to May,—when the solar rays are rarely intercepted by clouds. In the cotton districts and on all parts of the elevated plateau above the ghauts the atmosphere is drier and clearer than on the littoral, and, consequently, more favourable for the employment of solar heat. As to using firewood for steam machinery in India, the country does not produce sufficient to cook the food of the people and for their carpentry. The periodical famines that have recently almost depopulated whole districts, through the failure of the periodical rains, are generally ascribed to the gradual denudation of the country of trees, for carpentry, firewood, and railway sleepers; and, consequently, forest conservancy and the best means of inducing the people to plant large numbers of trees are recognised as new problems which the Government has to struggle with. Old residents in India remember ranges of hills, now as bald as a billiard ball, to have been formerly covered with trees; for instance, the ridge near Ahmednagar, in the Deccan, a district in which the recent famines have been

severely felt. It is not generally known, in Europe, that, in India, the manure of herbivorous animals is used as fuel, to cook the people's food, and that cowdung, one of the five sacred products of the cow, is employed for the floors of their houses and verandahs as bees' wax is used for the floors in France; thus depriving the land of the manure which, in western countries, would be used to fertilize it.

If solar heat were used, whenever practicable, by the people, to cook their food, and also for driving steam machinery, this evil would be partially remedied.

I took up the study of the question of the utilization of solar heat, about eighteen months ago, and have devoted all my leisure time to it, with the zeal and enthusiasm that the study of an interesting and difficult problem is calculated to excite. Having conclusively solved it, I have done all that lies in my power. I have neither the capital, the time, nor the practical knowledge required to conduct any business in which steam machinery is used. I know now that the "governors" of a steam engine are the two iron globes which revolve above it, and not, as I had supposed, the two men who lubricate the machine and feed the boiler with coals. That is nearly the extent of my knowledge of steam machinery; I am not likely, therefore, to start a steam engine on my own account. It is for some practical man, possessed of capital and enterprise, to take the matter up on the information contained in this book, and with the assistance and further information which I will gladly give him.

In default of private enterprise, the matter is of sufficient importance, I respectfully submit, for the Government of Her Imperial Majesty in India to take an interest in it. I have always understood one of the principal objects of the Government of India to be "the development of

the resources of the country ;" if so, the gratuitous and inexhaustible supply of solar heat with which the country is blessed by a beneficent Providence, in compensation for the absence of coal and the scarcity of wood, may surely be considered to be one of the most important "resources" that require to be developed. The expense of setting up a large steam boiler, and constructing the mirrors on the plan I have described, in order to ascertain whether I have exaggerated the extent to which solar heat can be used, would not require a very great outlay of money in comparison with the sums that have been expended in experimental essays, which by no means bore such fair promise of a profitable result.